FRONTALIS EMG FEEDBACK

SHEIN

FRONTALIS EMG BIOFEEDBACK-ASSISTED RELAXATION TRAINING IN CEREBRAL PALSY: TWO CASE STUDIES

By

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ABSTRACT

The effectiveness of auditory frontalis EMG feedback as a means of teaching general relaxation to spastic and athetoid cerebral palsy individuals was investigated in a pilot study. It was hypothesized that an increase in voluntary ability to reduce levels of muscle activity would translate into improved functional skills and act as an effective coping response in dealing with stress and anxiety.

Two subjects - one athetoid (female; 16 years old) and the other spastic (male; 19 years old were studied in depth, each through the use of an A-B-A single-subject design, where the B phase consisted of ten 15-minute sessions of auditory feedback of the frontalis muscle. Generalization of relaxation was assessed by monitoring forearm flexor and extensor muscle activity, peripheral skin temperature, and respiration rate. A Tektronix 4051 desktop computer was utilized to facilitate data management. In addition to the physiological measures, functional evaluations were conducted prior to and after training and a questionnaire was answered by the subject's relatives. Although there was no clear tendency for either subject to reduce absolute levels of EMG, one subject demonstrated a striking reduction in variability of muscle activity across sessions. Functional assessments for these subjects indicated mild to moderate improvements.

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CHAPTER I

INTRODUCTION

1.0 Background

Cerebral palsy is a neurologically-based disorder with primary involvement in the area of motor dysfunction, but which can also be manifested in perceptual and intellectual deficits. It arises from brain damage at or near the time of birth through a variety of causes: pre-natally, for example due to German Measles; natally, for example due to anoxia during the birth process; and post-natally, for example due to traumatic head injury. The brain damage can result from a lack of oxygen, traumatic tissue damage or an improper balance of chemical nutrients to the brain, which is going through a rapid and crucial stage of development at this time. Some people may be only mildly affected, so that the condition is barely noticeable, while others may be so severely affected that they cannot physically do anything for themselves - even though they may be very intelligent. The degree of involvement varies depending upon the extent of underlying organic damage

and in order to express a particular type of involvement of cerebral palsy, descriptive categories have been devised with such names as spastic, athetoid, and ataxic. These names, however, only provide a gross description and say little about an individual's abilities or disabilities.

The traditional treatment of cerebral palsy involves a multidisciplinary approach which includes physiotherapy, occupational therapy, speech therapy, and surgical management aimed at correcting orthopaedic deformities arising from an imbalance of an individual's muscle activity (both hypotonicity and hypertonicity). Other treatments less radical than surgery have also been employed to bring relief from hypertonic or spastic muscles. Pharmacotherapy with medications such as diazepam (Valium) and dantrolene sodium (Dantrium) are regularly prescribed as muscle relaxants. Unfortunately, problems develop with the use of medication. Although effective in the suppression of hypertonicity, medication can interfere with purposeful movement and may have negative side effects, for example sedation, drowsiness, bizzare behaviour, and loss of head control (Landau, 1974). Developing a tolerance to medication over time also poses difficulties for the cerebral palsy individual.

Surgical intervention is also not without its drawbacks. Relief may be only temporary, and negative side effects to the health of the patient may follow an operation, including psychological trauma. As well, the patient must spend time in acute care at a hospital at a high financial cost.

A basic principle of all interventions with cerebral palsy, regardless of the specific method used is the physical reeducation of the body's motor apparatus in order to facilitate more adequate functioning. In

this respect relaxation of muscle tone is a frequent goal in the habilitation of the individual with cerebral palsy. According to Pohl (1950) "the first endeavour in treatment is to reduce excessive tension and/or involuntary activity of the muscle" (pg. 27).

A number of approaches to reduce hypertonicity have been developed in the field of physiotherapy and these include "facilitation" techniques such as proper positioning, seating, vibration, massage, and guided or passive movement. All of these techniques have as a theoretical platform, the assumption that normalization of muscle tone will allow the individual with cerebral palsy to achieve more normal and functional motor patterns. Unfortunately these methods, in addition to surgery and medication, are all applied to a patient who is only a passive recipient of treatment which acts unconsciously. Spasticity is not only under unconscious control but also under cortical or conscious control and the above-mentioned techniques do not always address this dual control.

Both Bobath (1971) and Rood (1956) physical therapy systems advocate and incorporate normalization of tone as part of their approach. It is important to recognize, however, that there is a paucity of hard scientific evidence which provide support for the use of any of the methods mentioned.

An approach to reduce levels of muscle hyperactivity, with scientific support, is the progressive relaxation technique developed by Edmund Jacobson in the 1930's. This method, which involves the sequential tensing and relaxing of specific muscle groups throughout the body, has an impressive data base regarding its effects with a non-neurologically disabled population. It has been suggested that progressive relaxation be applied with cerebral palsy subjects. However, only one such study has appeared in the

literature. Ortega (1978) performed this study using the Minnesota Rate of Manipulation Test (MRMT) as the primary dependent measure. This test measures hand function through the timing of placing round disks into appropriate holes. Four adult (age range: 29-49) subjects with cerebral palsy, employed in a sheltered workshop, practiced progressive relaxation every day during experimental periods that were different for each subject (12,15,20, and 25 days). An overall improvement of 24% (range: 11% - 40%) for all subjects was demonstrated by MRMT scores. Interestingly, subjective claims of improvements in other areas were also reported. A three-week follow-up did, however, indicate a slight deterioration.

It must be noted that caution should be exercised when drawing conclusions from this and other relaxation studies in cerebral palsy for a number of reasons: (1) there needs to be a control for sitting quietly; (2) the possibility exists for a higher task motivation during the experiment; (3) the ecological validity of dependent measures is questionable; (4) there is not enough data regarding carryover effects; and (5) there is a need to know more about mechanisms of change.

A parallel approach to progressive relaxation has evolved through the utilization of electromyographic (EMG) biofeedback because not all persons with cerebral palsy can practice progressive relaxation exercises due to their degree of involvement. As well, feedback of muscle activity has been shown to ameliorate the effects of relaxation. A serendipitous discovery was made by Finley (1976) who was trying to teach a subject with cerebral palsy sensorimotor EEG rhythm but could not get accurate recording of brain-wave activity due to extremely high levels of frontalis EMG. He then trained the subject to reduce frontalis EMG with no therapeutic intent but

found that the subject showed numerous benefits such as functional improvements. Two subsequent studies by Finley (discussed in more detail in chapter IV) using frontalis EMG feedback resulted in both learned reduction of frontalis EMG levels and mild to moderate gains in a wide range of functional abilities in subjects with cerebral palsy.

1.1 Aim of study

The aim of this research study was to replicate and extend Finley's findings on a pilot study level. That is, to teach individuals with cerebral palsy to relax using frontalis EMG feedback as an aid to general relaxation and to assess the effectiveness through objective measurements of physiological and functional clinical measures. It was decided to proceed on a pilot study level in order to identify problems with such an approach and to become more familiar with the technique so that it could be applied to a larger group of subjects after refinement. In an attempt to retain maximum control over the experimental variables and to clearly identify the benefits of EMG feedback, only auditory frontalis EMG feedback was used for training.

CHAPTER II

METHODS AND MATERIALS

2.0 Introduction

A pilot study incorporating a single-subject A-B-A design was employed to determine whether auditory frontalis EMG biofeedback relaxation training in a cerebral palsy individual reduces general bodily arousal levels. It was hoped that this would lead to an improvement in functional motor skills and provide a coping response with which an individual with cerebral palsy could effectively deal with stress and anxiety.

EMG from three muscle sites, frontalis, right forearm extensors, and right forearm flexors, as well as peripheral surface temperature of the right index finger and respiration rate were monitored to provide an objective measure of the physiological aspects of relaxation.

Following a typical biofeedback paradigm, auditory feedback of frontalis activity was provided in phase B to assist relaxation. The other

parameters merely served as observational indices. To preclude any confounding variables the experimental setting remained constant, no specific relaxation instructions were given, and no additional therapies or medication changes were allowed.

This chapter serves to describe the experimental design and protocol in addition to experimental facilities and data management.

2.1 Subjects

Two young adults with cerebral palsy, one female (B.S.), aged 16, and the other, male (T.D.), aged 19, were selected for this study. B.S. was a moderately involved athetoid quadriplegic, ambulatory and verbal but with coordination and speech deficiencies. On the other hand T.D. was a severely involved spastic quadriplegic, non-verbal, and non-ambulatory. He was, however, independently mobile with a manual wheelchair. More comprehensive descriptions are provided in sections 3.1.1 and 3.2.1.

Both subjects were given an explanation of the nature of the study including the fact that no beneficial or therapeutic effects were promised as a result of their participation. Informed consent (see Appendix A-1) was obtained prior to beginning the study which had been approved by the Research Review Committee of the Ontario Crippled Children's Centre, Toronto.

2.2 Experimental facility

All sessions were conducted in a 4x5 metre partitioned area of the Biofeedback Research Project's work area. Efforts were made to provide a stable environment conducive to relaxation by attenuating the brightness of the lights, and by eliminating telephone calls and/or other interruptions.

In order not to interfere with the subject, all monitoring equipment was kept away from the subject's view behind a partition and cables from the EMG and temperature sensors led to their respective monitors. A comfortable, reclining easy chair was available but only B.S. was able to make use of it as T.D. was confined to a wheelchair.

EMG signals from the three muscle sites were processed through three feedback myograph units Model 1700, Autogen System Incorporated, Berkeley, California. Built-in meters on each device indicated instantaneous muscle activity and the integrated, bandpass filtered EMG output was recorded and further processed through a Tektronix 4051 desktop computer.

One unit monitoring frontalis activity provided feedback in the form of a continuous clicking noise that varied in rate logarithmically to the EMG signal. This feedback was presented continuously in an analog form, during the intervention period of phase B. A fast rate of clicks represented a tight muscle and conversely the rate of clicks slowed down as the muscle relaxed.

Beckman miniature bipolar surface electrodes were arranged in sets of three (two active and one reference electrode)(see Appendix A-5) over the three appropriate muscle sites in order to pick up the EMG activity. Spacing and location remained constant between sessions so that signal differences due to placement were minimized.

A single Yellow Springs Precision Thermistor attached to the right index finger sensed peripheral skin temperature. This thermistor was used in conjunction with a Model 2000b thermometer, Autogen System Incorporated, Berkeley, California, which in turn fed into the Tektronix 4051 which recorded and further processed the temperature signal. The thermometer had a

capability of resolving absolute and derivative temperatures to 0.025°F (0.045°C). Derivative temperature refers to the rate of change of temperature which the Autogen 2000b thermometer is capable of determining.

Another Autogen 2000b thermometer was employed in monitoring respiration rate in conjunction with a thermistor taped below the subject's nostril and with an OCCC Time Event Counter (TEC). As the person exhaled, the thermometer would sense a positive change in temperature and produce a constant positive DC signal that the TEC could detect. The TEC was thus able to count the number of exhalations. When the person inhaled, the thermometer registered a negative change in temperature as cool air entered the nose. The TEC then waited until it could detect the next increase in temperature that occurred with the following exhalation at which point it incremented again. Due to an inability to interface the TEC with the Tektronix 4051, data collection was manually performed.

Signals from the three myographs and single thermometer passed through an AMS GPIB analog-to-digital (A/D) convertor prior to manipulation by the Tektronix 4051 and storage on magnetic tape. The use of a desktop computer simplified data collection and management and increased the richness of information obtained by being able to sample the signals much faster and more objectively than could be achieved manually. Software was written in BASIC (see Appendix A-3) and included routines to graph the data from each of the four channels immediately after the conclusion of a session. Statistical programmes were also written to handle the management of processed data.

2.3 Protocol

2.3.1 Experimental design

A single-subject ABA design was selected for study incorporating the following phases: pre-biofeedback evaluation; one adaptation session; three baseline recordings of physiological indices (A_1); ten frontal EMG biofeedback sessions (B); three baseline sessions (A_2); and post-biofeedback reevaluation. During the baseline recordings of phase A_1, the subjects were asked to try to relax on their own for a 15-minute period following 10 minutes of remaining still. Auditory feedback in the form of clicks was provided continuously for a 15-minute intervention period in phase B of the study. Again this was preceded by a 10-minute period of remaining still that constituted a baseline for that particular session. Phase A_2 included equivalent sessions to A_1 except there was no need for an adaptation session.

In all sessions no specific instructions on relaxation strategies (such as progressive relaxation or autogenic suggestions) were given. Prior to the 10-minute baseline period of each session, the subject was asked to remain as still as was possible and not be concerned with any uncontrollable movements. The simple and brief instructions for the 15-minute intervention period were to attempt relaxation and to use the clicks in phase B as an indicator of tension that should be reduced.

At the conclusion of each session, the data collected by the desktop computer was stored on magnetic tape and displayed in the form of graphs so that the experimenter could visually interpret the subject's performance that day.

2.3.2 Pre- and post-biofeedback evaluations

Clinical evaluations were undertaken immediately prior to and following the baseline recording sessions in phases A_1 and A_2. It was necessary, however, to administer individualized assessments due to the different manifestations associated with cerebral palsy that B.S. and T.D. exhibited.

Speech was identified as one target behaviour that B.S. wished to improve. Therefore, speech (oral muscular function) was evaluated. This evaluation included physiological examinations of the oral mechanism, diadochokinetic testing (sustaining vowel sounds), time to complete one statement, word and phrase repetition measurements, and an articulation test. Since B.S was ambulatory and had hand function, gait, hand function, and psychological measures were also assessed. The Minnesota Rate of Manipulation (1969) test was applied to evaluate hand function in conjunction with a finger tapping test. Digit span, picture completion, picture arrangement, block design, object assembly, coding, fluency, sentence memory, category, and trail making provided psychological measurements of B.S.'s performance.

Assessments of T.D. were not as encompassing as with B.S. because of his severe physical disability. Since T.D. had expressed a desire to increase his ability to move both his arms his range of motion (ROM) of both arms was assessed. A functional skill, typing with a head stick, was also identified as a target behaviour he wished improved. Therefore, to satisfy T.D's criteria for improvement this was adopted as a clinical dependent measure and a typing exercise was administered. This exercise consisted of two controlled 10-minute trials of typing as much of a paragraph as possible from a typing manual. A different paragraph was used in each trial, but the

same paragraphs were used in both pre- and post-biofeedback evaluations.

In addition to the assessments described above both subjects had a family member complete a questionnaire (see Appendix A-2) and rate the subject in the areas of physical characteristics, functional activities, and psychosocial factors. The rating consisted of a comparison of his/her behaviours, abilities, and/or qualities since relaxation training began, with the period prior to training on an eleven point scale.

2.3.3 Adaptation session

Prior to the initial baseline recording session of phase A_1 both subjects were given an adaptation session in order to adjust to the new situation. They were not asked specifically to relax but to simply play with the feedback to get a feel for how they were able to control the rate of clicks.

2.3.4 Experimental set-up

At the start of each session the subject was seated in the partitioned area of the room. B.S. sat comfortably in the reclining chair while T.D. remained in his wheelchair throughout the session because of his dependence upon the wheelchair. The areas of skin over the three muscle sites: frontalis; right forearm extensors; and right forearm flexors, were thoroughly but gently rubbed with an alcohol swab. This swabbing preceded the attachment of electrodes and served to remove the dead epidermal layer of skin as well as surface body oils in order to achieve good electrode contact with signal-to-sensor continuity. The hair on T.D.'s forearm extensor electrode site was also shaven to ensure a clean signal.

To facilitate the contact between the electrode and the skin, a conductive gel was used to fill the depression or cup of the electrode. Each of the three electrode assemblies consisted of two active and one reference electrodes and these were attached to the skin with adhesive electrode collars. The reference electrode was placed centrally between the other two sensors with a constant centre-to-centre spacing of 1.5 cm. Care was taken to ensure that the same locations were used during each session.

A temperature thermistor was snugly attached by means of Micropore tape to the dorsal side of the distal phalange (fingerprint area) of the right index finger. It was necessary to be careful not to have the tape so snug as to affect circulation in the fingertip. A second thermistor was taped directly below one of the nostrils in order to monitor respiration rate.

Shielded cables linked the electrodes and thermistors to their respective monitoring units and after securing the sensors the quality of each attachment was checked. For the electrodes this meant performing an impedance rating of each active electrode utilizing the built-in impedance check mode of the Autogen 1700 myographs. Any electrode with an impedance greater than 70,000 ohms was checked and if need be removed, the skin prepared again, and the electrode reapplied or replaced. The temperature monitored by the finger thermistor was briefly examined to see that it was reasonable and respiration rate was checked by observing that the Autogen 2000b and TEC responded to changes in temperature as the subject inhaled and exhaled.

Computer data acquisition began once assured of proper sensor connections. Counting of breaths on the TEC also began at the same time. At

the end of each minute, average integrated EMG (IEMG) values (in microvolts) and the average fingertip temperature (in °F) were displayed in tabular form on the Tektronix 4051 graphics screen along with corresponding standard deviations. It must be noted that the microvolt values refer to the processed EMG from the Autogen units and may not be equivalent to microvolt values from another manufacturer's myograph unit (see Appendix A-5).

2.4 Signal processing

The EMG signal from each muscle underwent significant processing prior to storage on magnetic tape. Initially, the signal was bandpass filtered between 100-200 Hz. through a filter with the following characteristics - high pass: 54 db/octave below 100 Hz.; and low pass: 24 db/octave above 200 Hz. This bandpass was selected because of its good artifact rejection characteristics, high signal-to-noise ratio, and allowance for a wide range of EMG activity within a particular scale setting. Experience has shown this last factor to be important when working with an individual with cerebral palsy as their muscle spasms can easily generate large quantities of EMG that can go out of range within a particular scale setting.

Following bandpass filtering, the signal was transformed into a DC signal between 0 and 3 volts which was linearly proportional to the integral average EMG. The filtered EMG was full-wave rectified, integrated and scaled/divided by the time constant of integration which was 50 msec. (see Appendix A-5). The audio click feedback varied with this signal, called instantaneous IEMG, at a logarithmically proportional rate.

Further smoothing of the signal was done prior to A/D conversion through a 2.2-second RC circuit (see Appendix A-5) because of computer proc-

essing time limitations. The fastest sampling rate that the Tektronix 4051 could handle so that the means and standard deviations could be computed and displayed each minute was 5 samples per second. With four channels of data collection this meant that each channel was sampled at 1.25 Hz. Since an additional channel was possible for future work a 2.2-second smoothing circuit (0.45 Hz. upper bandpass filter) was constructed which the IEMG signal passed through. This smoothed the IEMG signal to satisfy the Nyquist requirement of having the sampling freqency (1.25 Hz.) at least twice the maximum frequency component of the signal (0.45 Hz.).

During each minute sixty samples from each of the four channels were collected. This took the first forty-eight seconds of each minute and the remaining twelve were spent computing means and standard deviations, and displaying these in tabular form. The constraints of BASIC programming and the physical characteristics of the Tektronix 4051 were responsible for this lengthy processing time. A simple comparison of the mean IEMG processed by the Textronix 4051 with the 50-second running-time IEMG average value displayed on a meter, on the Autogen 1700, revealed that the mean IEMG values were the same. However, the Autogen 1700 was unable to provide a standard deviation or indication of variation as the computer was able to do.

2.5 Statistical management of data

Two BASIC programmes (see Appendix A-3 and A-4) were devised, one to acquire the data and calculate means and standard deviations and the other to summarize the data and perform correlations between the three EMG and single temperature parameters. A standard programme was written and used to calculate the t-statistics for the in-session difference between the

intervention period and the baseline period. Respiration rate was not included in the programme as it was not included in the computer data acquisition system, and was therefore analysed by hand.

For analysis purposes, only the last 10 minutes of the intervention period was compared with the 10-minute baseline. The same time period was chosen so that the two groups of data would have an equal number of observations and also experience had shown that the first few minutes following the introduction of feedback were needed to adjust to the task of controlling the feedback. For the remainder of the discussion the last 10 minutes of the 15-minute intervention period will be referred to as the intervention period or feedback period in phase B.

The following values were computed to summarize the minute means and standard deviations of EMG and peripheral skin temperature for each session:

1. baseline period average;
2. intervention or feedback period average;
3. average change between baseline and intervention or feedback period;
4. percent average change between baseline and intervention or feedback period;
5. standard deviation of baseline average; and
6. standard deviation of intervention or feedback period average.

All possible combinations of EMG and temperature means and standard deviations were then tested for significant correlation ($P<0.05$) within each of the sixteen session. The following formulae were utilized in computing the correlation coefficients, r_{xy}:

$$r_{xy} = \frac{S_{xy}}{S_x S_y}$$

$$S_{xy} = \frac{\left[\sum xy - \frac{\sum x \sum y}{N}\right]}{N-1}$$

$$S_x = \sqrt{\frac{N \sum x^2 - \left(\sum x\right)^2}{N(N-1)}}$$

$$S_y = \sqrt{\frac{N \sum y^2 - \left(\sum y\right)^2}{N(N-1)}}$$

For N=10 the correlation coefficient, r_{xy}, must be greater than 0.6319 to be significant using a two-tail test at a 5% level of significance (from Table VII of Fisher and Yates: Statistical Tables for Biological, Agricultural and Medical Research).

CHAPTER III

RESULTS

3.0 Introduction

Each subject participated in a total of sixteen biofeedback sessions in addition to an introductory session and pre- and post- biofeedback evaluations. Transportation constraints limited B.S. to attending three times per week and T.D. twice weekly.

Due to the difference in severity and manifestations of cerebral palsy exhibited between subjects, observations were treated as separate following a single-subject A-B-A design. Three principal areas of interest were examined and are reported in this chapter. These include: pre- and post- biofeedback evaluations; differences in physiological parameters between intervention or feedback period and the baseline period within each and between sessions; and correlations between physiological parameters. Physiological parameters consisted of: surface EMG from frontales, right forearm extensor and right forearm flexor muscles; peripheral skin temperature of the right index finger; and respiration rate.

3.1 Case study 1: Subject B.S.

3.1.1 General description

B.S. was a 16-year-old female moderately involved with athetoid cerebral palsy and who was quite familiar with the OCCC. She was ambulatory and verbal but exhibited uncoordination while walking and grasping objects, and her speech was quite unintelligible except to a very attentive listener. Socially, B.S. was active but she appeared to be immature in developing relationships with others and she easily got 'crushes' on males around her. This in fact presented a substantial problem with the male experimenters and may have adversely affected the impact of the relaxation training.

3.1.2 Effects of biofeedback training on physiological parameters

3.1.2.1 Surface EMG

Surface EMG signals from frontalis, right forearm extensor, and right forearm flexor muscles were recorded throughout the duration of each session. On-going processing by a Tektronix 4051 desktop computer provided mean values and their corresponding standard deviations for each minute from the EMG signals. A typical graph indicating mean and standard deviation values for IEMG that the Tektronix 4051 was able to produce is shown in Figure 3.1. Graphs for each muscle and session were produced and visually inspected prior to further analysis. Period averages are presented in Figures 3.2 and 3.3 for means and standard deviations respectively in the form of a separate graph for each muscle site. Two lines on each graph are drawn: one to represent an average of the baseline period; and the other to reflect an average activity during the intervention or feedback period (last 10 minutes of the biofeedback session).

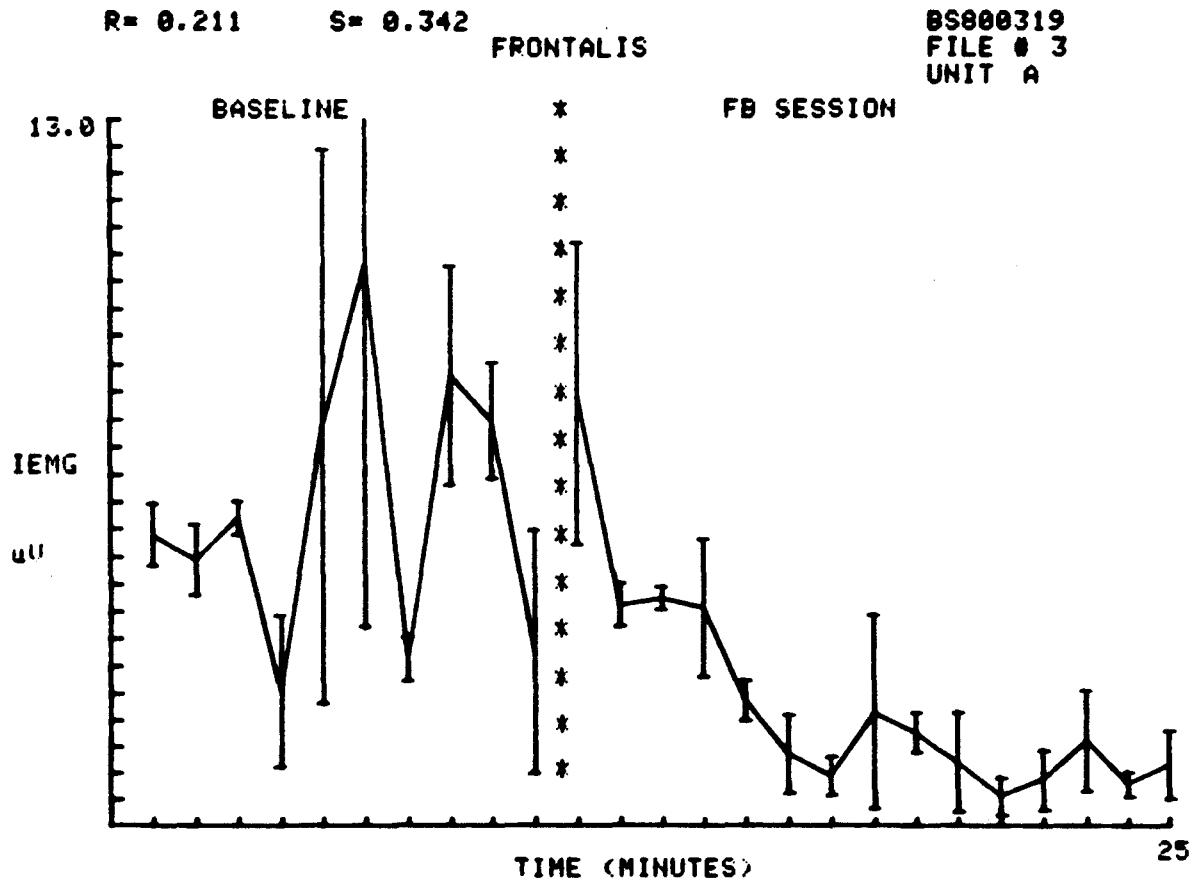


Figure 3.1: Typical graph illustrating IEMG of one muscle over time during a session indicating mean values ± 1 standard deviation at each minute for subject B.S.

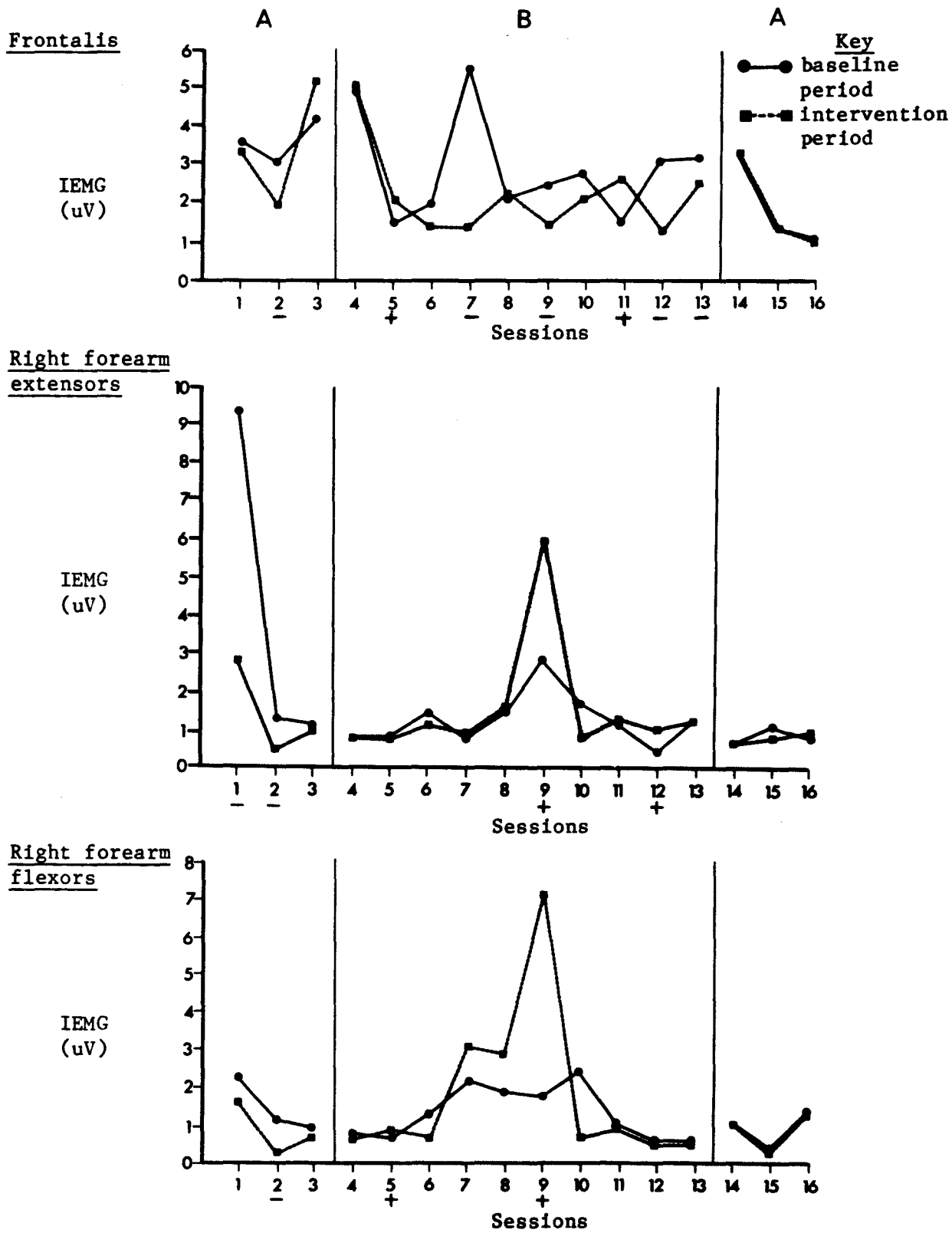


Figure 3.2: Average IEMG mean levels of each muscle for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject B.S.

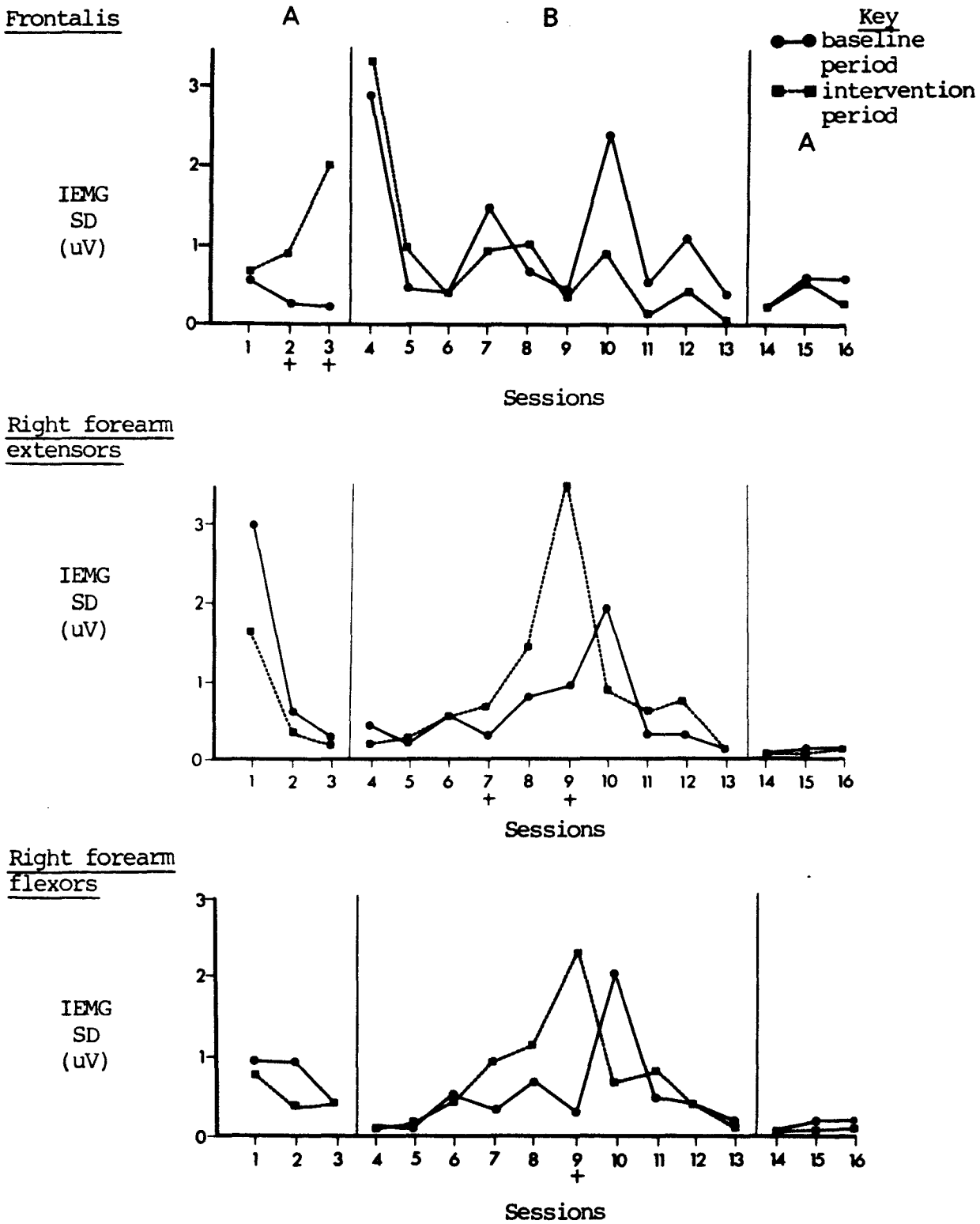


Figure 3.3: Average IEMG standard deviations (SD) of each muscle for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject B.S.

In the same figures a '+' or '-' sign below a session number indicates whether a significant ($P<0.05$, $t_{18}>2.101$) change between the baseline period and feedback period occurred and in what direction the average value moved. An examination of Figure 3.2 reveals that the greatest number of significant changes from baseline to feedback period (4 out of 6 negative changes in FB phase B) appear in frontalis EMG.

Absolute change in EMG levels from no-feedback phase A_1 to feedback phase B is greatest with the right forearm extensor. This can be attributed to B.S. lifting her wrist playfully during the first session resulting initially with high EMG readings. High extensor and flexor EMG levels in mid phase B can also be ascribed to B.S. voluntarily moving her hand about contrary to instructions. During this time she had grown somewhat bored with the sessions. Therefore, at that point (after session 9) the importance of relaxation was discussed again in more detail with her and her performance improved afterwards.

Much more dramatic were the trends exhibited in Figure 3.3 with standard deviation period averages. There are clear trends in reducing EMG standard deviations in all muscles through the course of the study, disregarding mid phase B where standard deviations were high as a result of B.S. moving her hand about. A comparison of phase A_2 with A_1 highlights the changes that occurred. The trend is most apparent with frontalis, the feedback trained muscle, and is further demonstrated in Figure 3.4b. In this figure, absolute changes in standard deviation between baseline and feedback periods are plotted across sessions and compared with a similar plot of mean changes in Figure 3.4a. It can be seen that while the plot of within session changes of mean values of EMG across sessions does not clearly indicate

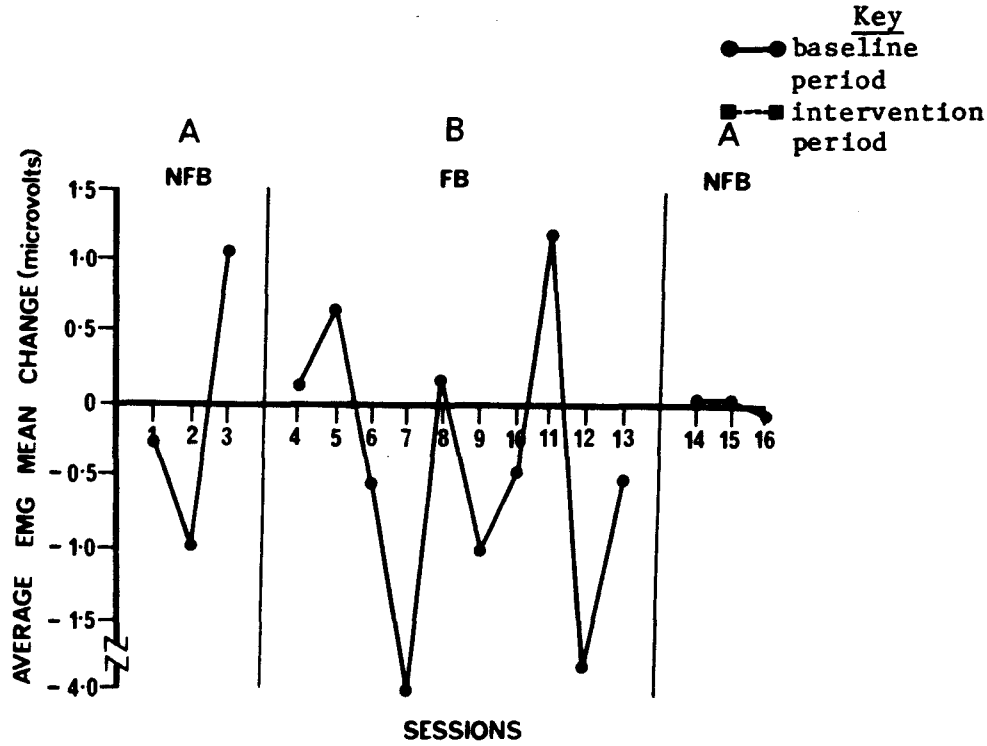


Figure 3.4a: Average change in frontalis mean IEMG across sessions derived from the difference between the last 10 minutes of the intervention period and a 10-minute baseline within each session for subject B.S.

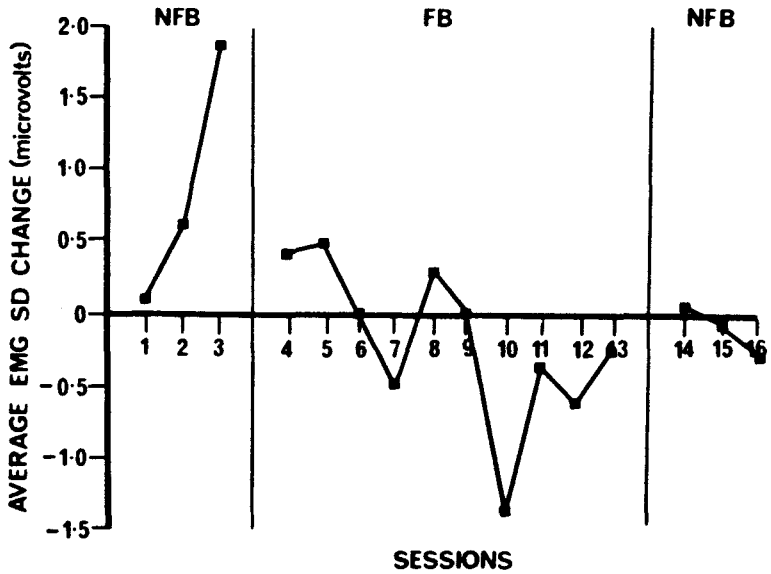


Figure 3.4b: Average change in frontalis EMG SD across sessions derived from the difference between the last 10 minutes of the intervention period and a 10-minute baseline within each session for subject B.S.

any change in B.S.'s ability to relax, there is a visible effect of the biofeedback sessions upon standard deviation changes across sessions.

Another observation that can be gleaned from Figure 3.4a and 3.4b is that certain contradictions exist, as evident in sessions 2 and 11, between EMG mean changes and standard deviation changes. In session 2 the average mean level of frontalis EMG decreases during the intervention period while average EMG standard deviations actually increase. The opposite situation to this - decreasing standard deviations with increasing mean levels occurs in session 11.

3.1.2.2 Peripheral skin temperature

Peripheral skin temperature from the right index finger was measured during each session and processed along with the EMG signals utilizing the Tektronix 4051 which calculated minute means and standard deviations. A typical session is exemplified by Figure 3.5 and period averages of means is illustrated for all sessions in Figure 3.6. Similar to the EMG plots one line represents the baseline period average while the other describes the intervention or feedback period average. Again a '+' or '-' sign below a session number indicates whether a significant ($P< 0.05, t_{18}>2.101$) change occurred from the baseline to the intervention or feedback period.

Although there did not appear to be a consistent pattern to absolute temperature, which certainly has a considerable range across sessions, there was a consistent and significant (11 out of 16 session) pattern of decreasing temperature during the intervention or feedback period. No visible trends were apparent with standard deviations.

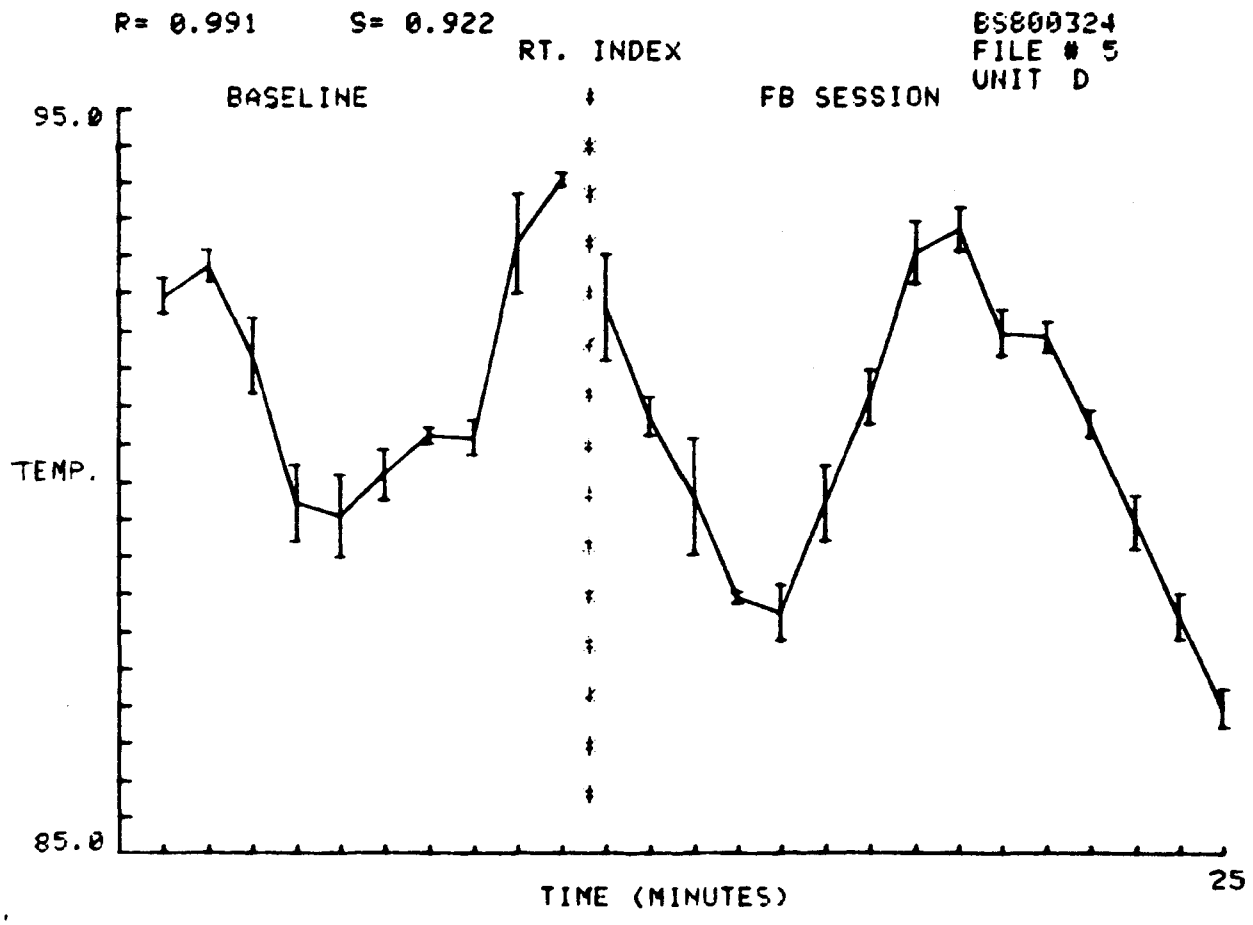


Figure 3.5: Typical graph illustrating peripheral skin temperature monitored at the right index fingertip during a session indicating mean values ± 1 standard deviation at each minute for subject B.S.

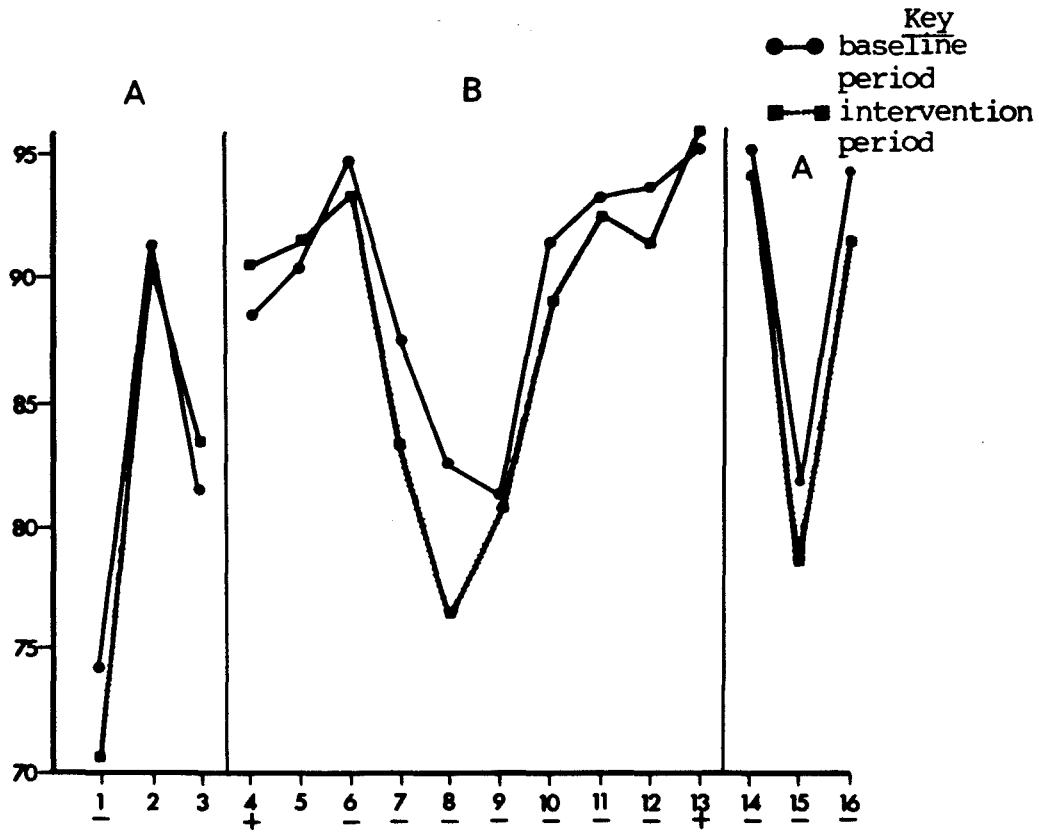


Figure 3.6: Average peripheral skin temperature mean values of the right index fingertip for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject B.S.

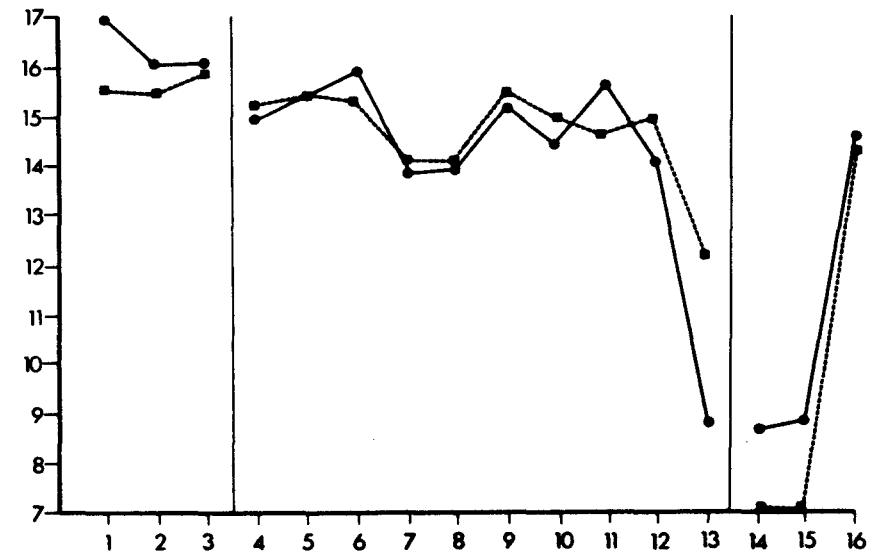


Figure 3.7: Average respiration rate mean values for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject B.S.

3.1.2.3 Respiration rate

Some difficulties were encountered in the collection of this measure as the thermistor occassionally shifted with upper lip movement. This was most likely due to irritation caused by the tape holding the thermistor in place. A shift meant that some breaths may have been missed. An additional error may have arisen in the manual reading of the exhalation rate on the TEC at the minute mark. It is possible that a minute had an extra breath attributed to it that should have been counted during the previous or following minute. Therefore, period averages were computed by using the total sum of breaths for that period divided by the period length (10 minutes). These period averages are plotted in Figure 3.7. No standard deviations were calculated.

Even when considering possible errors there was a rather clear decrease in respiration by the end of the study. It may be, however, that B.S. became more comfortable with the experimentation over time and, as a result, breathed in a more relaxed manner.

3.1.3 Correlations between physiological parameters

In order to test the hypothesis that relaxation of the frontalis muscle will lead to "general relaxation", correlations between the various physiological parameters were analysed. Respiration rate was, however, excluded as it was not part of the computer-aided data acquisition system and recorded minute values were often unreliable.

Six possible combinations for correlation analysis exist between the physiological indices. These are: frontalis IEMG/forearm extensor IEMG; frontalis IEMG/forearm flexor IEMG; frontalis IEMG/index finger temperature;

CORRELATION		SESSION															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	AB															+	
	AC												+				
between	AD	-	-										-				
Mean	BC	+	+			+	+					+		+	+	+	+
values	BD																-
	CD																
	AB													+			
	AC			+									+	+			
between	AD												+				
SD	BC	+	+	+	+	+	+	+	+		+	+		+		+	+
values	BD								+					+	+		
	CD								+	+				+			
	AA		+	+	+	+		+			+	+	+	+	+	+	+
between	BB	+	+	+		+		+	+	+	+	+	+	+	+	+	+
Mean and	CC	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
SD values	DD																

Table 3.1 Significant correlations ($P<0.05$) indicating direction of correlation between phyiological parameters for subject B.S. during baseline period (minutes 1-10)

A - frontalis EMG
B - right forearm extensor EMG
C - right forearm flexor EMG
D - right index finger temperature

CORRELATION		SESSION															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	AB					+	+						+				
	AC			+							+					-	
between	AD										+	-					
Mean	BC	+	+		+		+		+		+	+		+	+	+	+
values	BD									-					-		
	CD								-	+	+	+					
	AB						+			+			+				
	AC																
between	AD				-												
SD	BC	+	+		+	+	+		+		+		+	+	+	+	
values	BD	+											+				
	CD	+										+	+				
	AA		+		+	+	+	+	+	+			+		+		+
between	BB	+	+	+	+		+		+	+	+	+	+	+	+	+	
Mean and	CC	+	+		+	+	+	+	+	+	+	+	+	+	+		+
SD values	DD	+															

Table 3.2 Significant correlations ($P<0.05$) indicating direction of correlation between phyiological parameters for subject B.S. during intervention period (minutes 16 - 25)

A - frontalis EMG
B - right forearm extensor EMG
C - right forearm flexor EMG
D - right index finger temperature

forearm extensor IEMG/forearm flexor IEMG; forearm extensor IEMG/index finger temperature; and forearm flexor IEMG/index finger temperature.

Correlation coefficients (see section 2.5) were computed for each of the above combinations between mean values alone and between standard deviation values alone for the baseline period and intervention or feedback period separately. Also, an additional correlation calculation was performed between mean values and their corresponding standard deviations for each of the four parameters. All of the correlation coefficients are reported in terms of their significance in Tables 3.1 and 3.2. Table 3.1 displays a matrix indicating significant correlation ($P<0.05$) and direction of correlation between physiological parameters across sessions during the baseline period. The intervention of feedback periods are similarly analysed and shown in Table 3.2. Immediately obvious is the strong correlation between a mean EMG value and its standard deviation in both periods. There is also a relatively strong positive correlation (indicated by high incidence) between the forearm extensor and flexor muscles which is not surprising considering that they are agonist/ antagonist muscles. Few correlations, however, exist between frontalis and the forearm muscles. During the feedback period there are three out of ten significant correlations (with both mean and standard deviation values) between frontalis and forearm extensors that did not exist during the baseline period of those sessions but little else can be discerned from the data.

3.1.4 Evaluations

3.1.4.1a Speech: Pre-biofeedback

This assessment was conducted and prepared by the Speech and Hearing Department of the OCCC. In a physiological examination of the oral mechanism B.S. demonstrated limited tongue movements and she was unable to lateralize her tongue which tended to retract on each voluntary attempt. Upon protrusion a mild tremor was noted. She illustrated great difficulty in elevating and depressing the tongue both within and outside the oral cavity. In order to assist in elevating her tongue outside of the mouth there was noticeable jaw movement from the mandible and lip. Smiling both on command and spontaneously was accomplished with good symmetry and movement.

Diadochokinetic testing demonstrated that B.S. was able to sustain vowel sounds as follows:

1) (ah) - 3 seconds
2) (o) - 4 seconds
3) (e) - 4 seconds
4) (o) - 3 seconds

where each time represents an average over several trials with each phonation. B.S. was able, however, to count to 10 on a single breath.

During word and phrase repetition tests B.S. had no difficulty in the repetition of single words and 2 or 3 word phrases. However intelligibility was greatly reduced in the repetition of longer sentences and there was an omission of articles. Voice quality was in a monotone and severely dysarthric and B.S. was only able to read one paragraph of phonetically balanced passage.

B.S. had the following errors in an articulation test:

- b/v in the final position
- k/p in the medial position
- all s and sh sounds were lateralized and sloppy
- t/ch in all positions
- t/th in initial position
- th omitted in medial and final position

- there were almost no blends of initial consonants present

3.1.4.1b Speech: Post-biofeedback

With regard to the functioning of B.S.'s oral musculature very little change was noticed. Some improvements were observed in sustaining vowel sounds as follows:

1. (ah) - 10 seconds - an increase of 7 seconds
2. (ou) - 8 seconds - an increase of 4 seconds
3. (e) - 4 seconds - no change
4. (o) - 5 seconds - an increase of 1 second

Also, B.S. was now able to count up to 15 on a single breath, an improvement of a count of 5.

Little if any change was noted for word and phrase repetition, voice quality, and articulation. However, the level of intelligibility of reading a phonetically balanced paragraph appeared to have improved subjectively to the examiner and there seemed to be more change in the production of final consonants.

3.1.4.2a Hand function and psychological measures: Pre-biofeedback

A summary of the findings of sixteen measures is provided in Table 3.3. These tests were conducted by a childhood developmental consultant for the OCCC Biofeedback Research Project.

3.1.4.2b Hand function and psychological measures: Post-biofeedback

These findings are listed with pre-biofeedback measures in Table 3.3. Out of a total of 16 measures no change was observed in 2 measures, decreased performance in 2 measures (5% and 18%) and improved performance in

Test	Measure	Pre-BFB	Post-BFB	Performance Change
WISC-R	Digit Span	RS-8 SS-4	RS-9 SS-5	+13%
	Picture Completion	RS-21 SS-9	RS-21 SS-9	0
	Picture Arrangement	RS-24 SS-7	RS-34 SS-10	+42%
	Block Design	RS-28 SS-6	RS-23 SS-5	-18%
	Object Assembly	RS-20 SS-6	RS-28 SS-6	-5%
	Coding	RS-19 SS-1	RS-28 SS-1	+47%
Fluency	$\bar{x}$ number	6.5	7	+ 8%
Sentence Memory	number correct	14	17	+21%
Category	Errors	71	35	+51%
Trails Making (9-14 Battery)	A - time	24"	17"	+21%
	- errors	0	0	
	B - time	47"	40"	+18%
	- errors	0	1	
	A+B - time	71"	57"	+20%
	- errors	0	1	
Finger Tapping	$\bar{x}$ number	14.33 lt.	15 lt.	+ 5%
		12 rt.	12 rt.	0
Minnesota Rate of Manipulate	Unilateral 1	4'09"	3'09"	
	2	3'59"	3'21"	
	Total	488"	390"	+20%
	Bilateral 1	4'55"	3'39"	
	2	3'40"	3'47"	
	Total	515"	446"	+13%

Table 3.3 Summary of hand function/psychological measures for subject B.S.

12 measures. The following is a breakdown of the distribution of improvements:

- increased 5 - 15% : 4 measures
- increased 16 - 30% : 5 measures
- increased 42 - 51% : 3 measures

With regard to the significance of these findings, it is difficult to make any conclusive statement since not enough is known about the effects of repeated assessment with this population. As well, there is not any data available to make valid comparisons between frontalis EMG biofeedback relaxation training and other treatment regimens.

3.1.4.3a Gait: Pre-biofeedback

In order to assess the effect of relaxation on B.S. walking a gait study of B.S. in the OCCC gait laboratory was undertaken. At this time the gait laboratory was in a stage of development and this assessment was more or less an exercise in using the facility for evaluation. Results from this pre-biofeedback assessment are discussed in conjunction with the posttreatment evaluation of gait.

3.1.4.3b Gait: Post-biofeedback

An identical gait study to the pre-treatment study was performed. Unfortunately, not all of the possible assessment techniques were operational during both studies and as a result, only information concerning the repeatability of joint angle-time histories were available for analysis. However, if treatment was successful in reducing random movements it would be expected that the repeatability of gait parameters would increase.

Two gait runs (pre- and post-treatment) during which the speed of walking was about 0.7 m/s. were compared. Somewhat surprisingly the second study showed a loss in repeatability with regard to knee versus hip and ankle versus knee angles for four footsteps. During this study the poor repeatability may be attributed to a major extent to the variability of hip angle at the onset of swing. The extension of the right hip at this time had a mean value of 25.7° $\pm$ 14.5° ($\pm$ SD) while on the left side, this value was 1.7° $\pm$ 1° of flexion. An odd reversal occurred in B.S.'s stance behaviour. In the first study she favoured her left side with a stance period of 0.97 $\pm$ 0.06 seconds. This contradicted with the second study where she favoured her right side spending 0.81 $\pm$ 0.07 seconds on that side during stance and only 0.65 $\pm$ 0.03 seconds on the left side.

In summary, B.S. did not show any improvement in walking and in fact her walking patterns appeared to be more variable or worse during the post training assessment. However, not a great deal of weight can be applied to the gait assessment as its validity is questionable with a person with athetoid cerebral palsy.

3.1.4.4 Questionnaire

The parents of B.S. rated her in a questionnaire (see Appendix A-2) comparing her behaviour, abilities, and/or qualities since relaxation training began with the period prior to training. Histogram summaries of their responses are presented in Figure 3.8 in each of the three categories. Category 1, physical characteristics, had eight out of eleven applicable ratings. Category 2, functional activities, had five out seven possible ratings applicable and the last category, psychosocial factors, had twelve,

Category 1: Physical characteristics

Rating Scale

5: most desirable change
0: no change
-5: most undesirable change

Category 2: Functional activities

Category 3: Psychosocial Activities

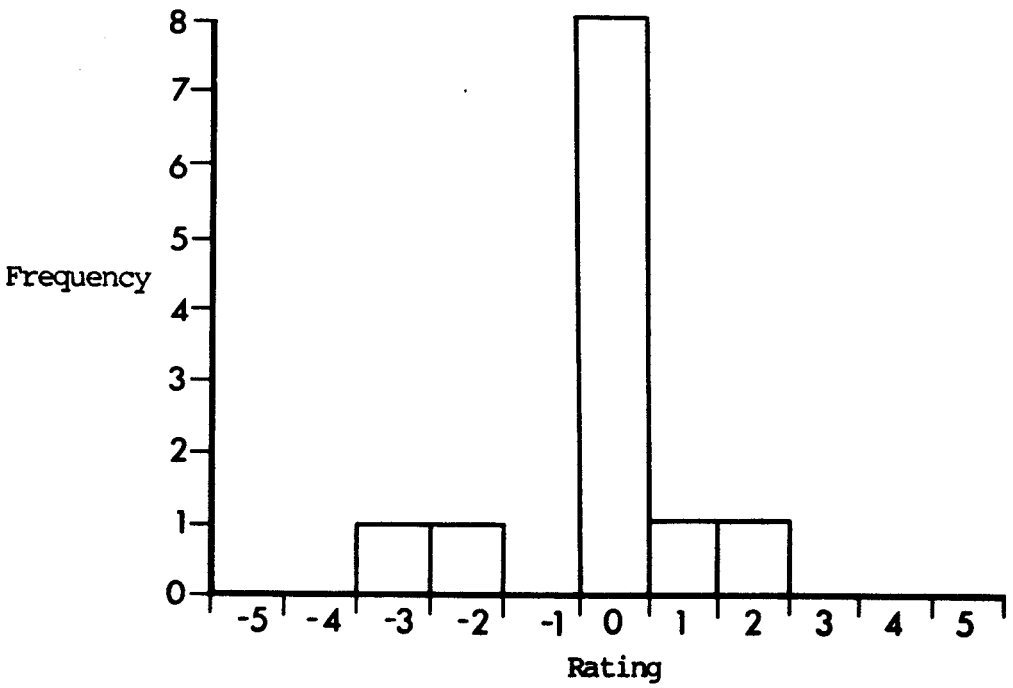


Figure 3.8: Summary of questionnaire rating B.S.'s behaviour, abilities, and quality changes since relaxation training began with the period prior to training.

all applicable, ratings. As can be seen from the histograms, very little change occurred from the parent's point of view. Positive changes appeared to be fairly well balanced with negative changes but with slightly more gains in the physical characteristics category. The most positive changes were in motor control and ability to relax on command. On the other hand the most negative change appeared to be in B.S.'s self-image category.

3.2 Case study 2: Subject T.D.

3.2.1 General description

T.D. was a 19-year-old severely involved male diagnosed as having predominantly spastic cerebral palsy with some athetosis. Although non-verbal, T.D. was quite communicative with a headstick pointer and alphabet board or typewriter. He was independently mobile with a manual wheelchair that he propelled with his feet but was unable to feed, dress, or transfer himself. Due to the nature of his cerebral palsy, spasticity varied day-by-day and with his level of stress or anxiety. Of normal intelligence and quite sociable T.D. felt that his greatest problems with uncontrolled spasicity and athetoid movements were when he was confronted with uncomfortable social situations such as being with a member of the opposite sex.

3.2.2 Effect of biofeedback training on physiological parameters

3.2.2.1 Surface EMG

An identical data base to that of subject B.S. was collected and analysed with T.D. Period averages are presented in Figure 3.9 and 3.10 for means and standard deviations respectively in the form of a separate graph for each muscle and each with two data lines to distinguish the base-

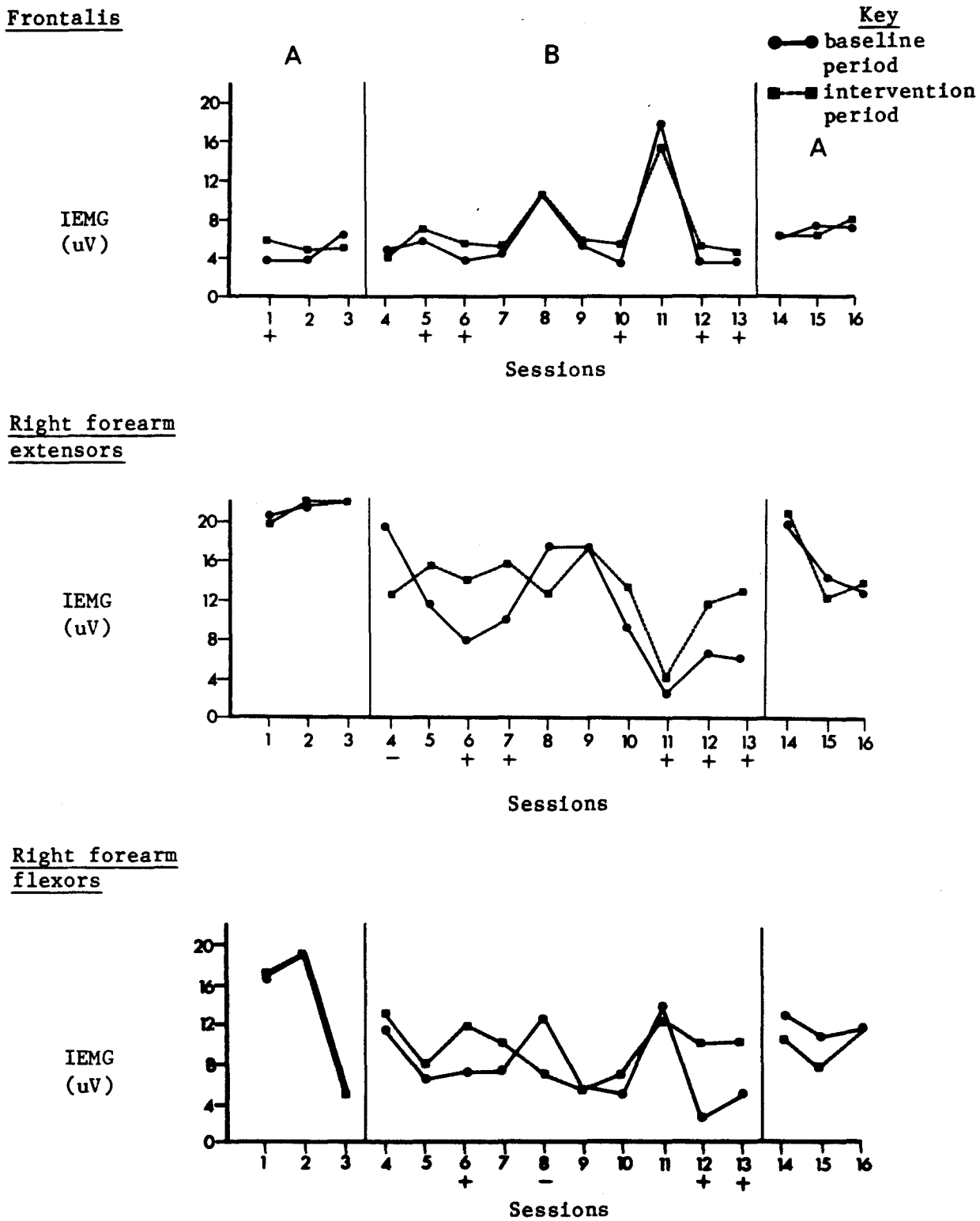


Figure 3.9: Average IEMG mean levels each muscle for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject T.D.

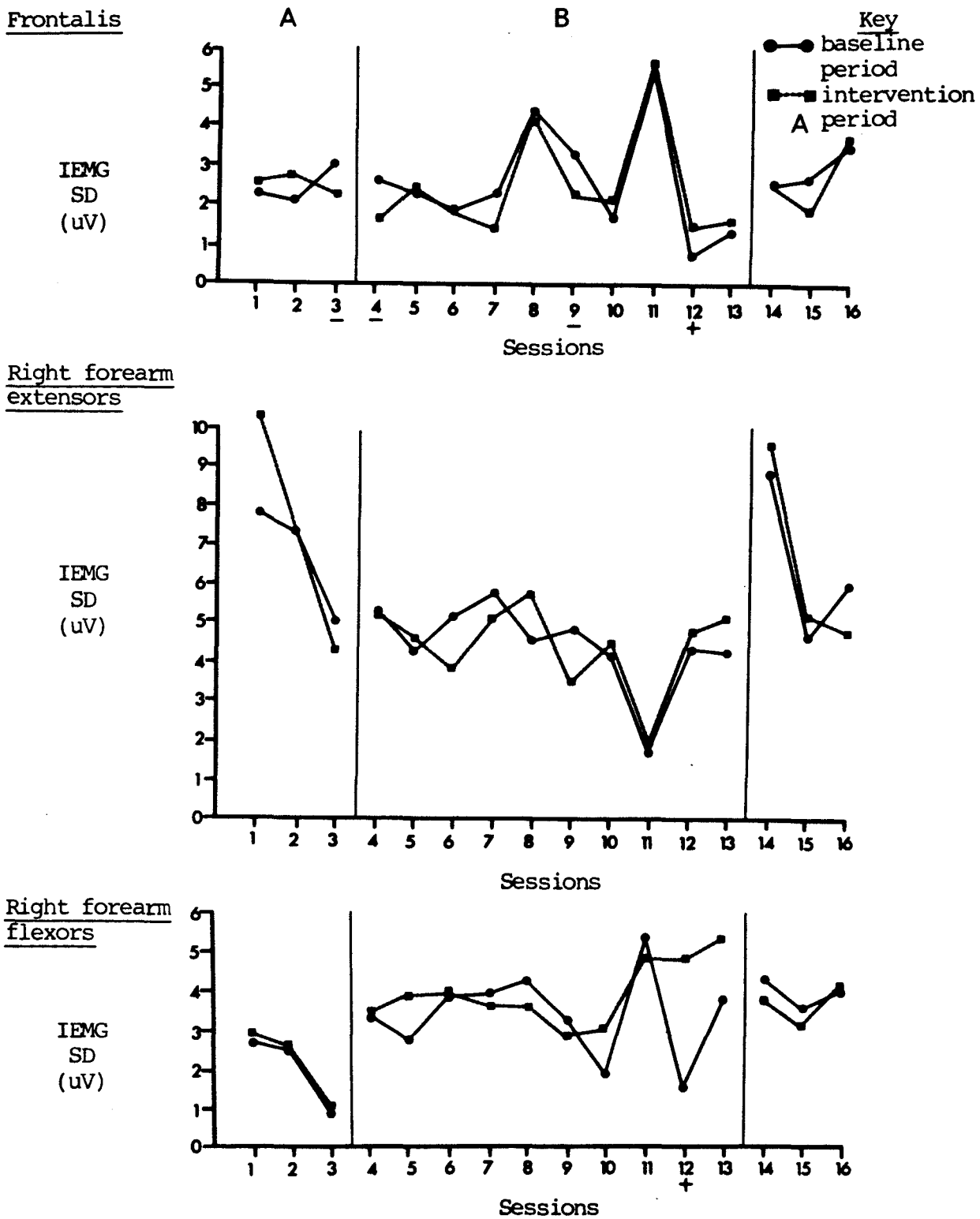


Figure 3.10: Average IEMG standard deviations (SD) of each muscle for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject T.D.

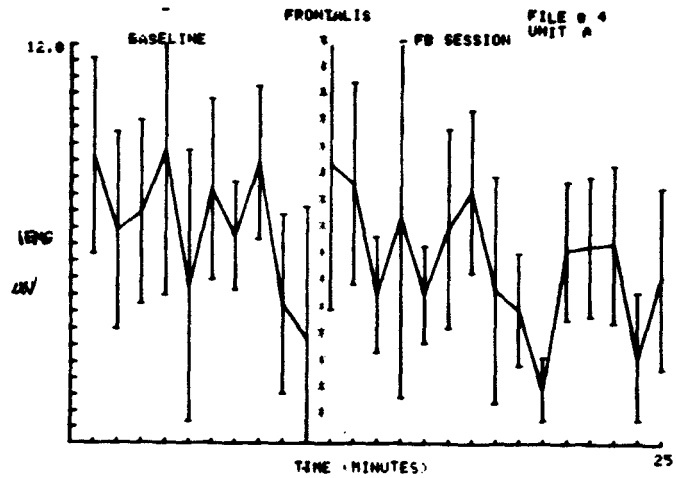
line from the intervention period. Significant differences between the two periods are marked below sessions numbers.

Of the three muscles - frontalis; right forearm extensors; and right forearm flexors, only the forearm extensors appeared to benefit from the training. This is demonstrated by a reduction in EMG after the introduction of frontalis feedback (phase B) and a reversal effect when the feedback is removed. Perhaps, a better understanding of T.D.'s reaction to feedback can be gained by comparing a typical phase A_1 session with a typical phase B session utilizing the computer produced graphs displaying minute mean EMG and standard deviation values during a session. Figure 3.11 illustrates the data from the three muscle sites during session 3 (phase A_1 and Figure 3.12 illustrates similar data during session 6 (phase B).

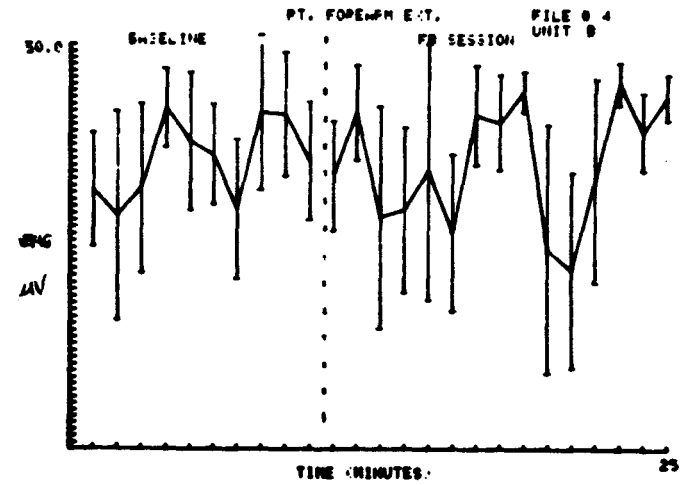
Very little difference between the intervention period (when asked to relax as best as possible) and the baseline period (when asked to remain still) is visible in the phase A_1 session. However, a typical pattern with feedback is shown in the phase B session. Immediately upon introduction of auditory frontalis feedback EMG levels increase, most dramatically in the forearm. After a few minutes they drop to or exceed baseline low levels, but they rise again and drop by the end of the session. This roller coaster effect was seen in several of the feedback sessions and could possibly result from T.D.'s anxiety with attempting to relax and remaining relaxed after reaching that state.

Unlike B.S., there was no training effect on T.D.'s frontalis EMG standard deviations. As mentioned previously, a much more pronounced training effect on standard deviations was demonstrated with the forearm extensor values.

Frontalis



Right Forearm Extensors



Right Forearm Flexors

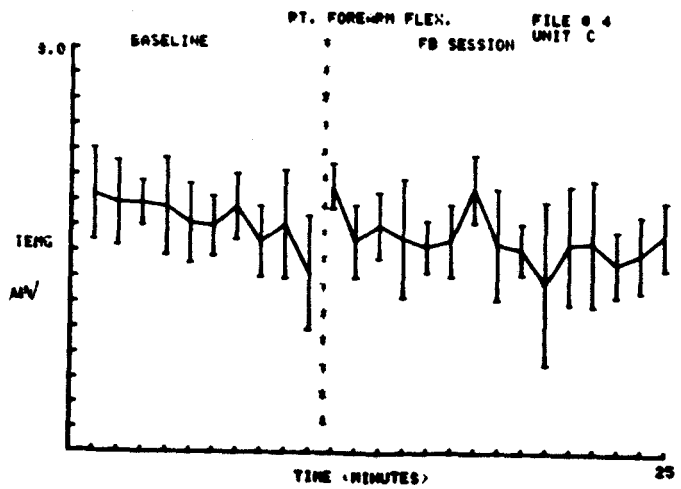
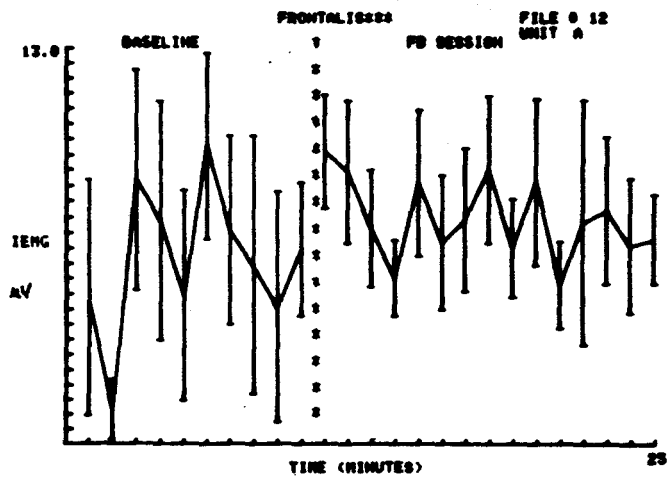
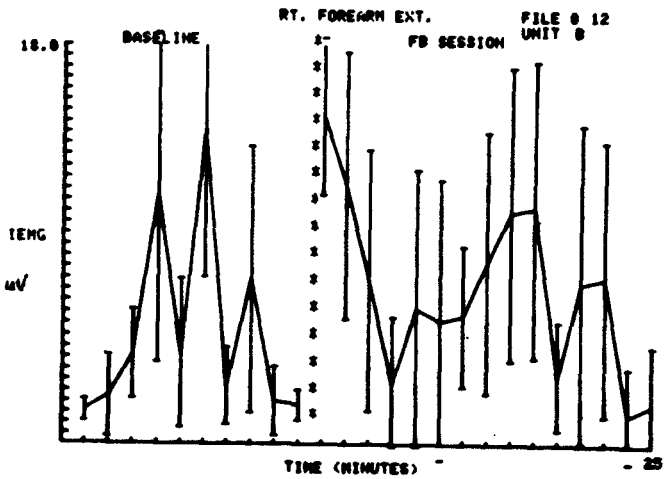


Figure 3.11: IEMG data from three muscle sites during session 3 (phase A_1) indicating mean $\pm$ 1 standard deviation at each minute for subject T.D.

Frontalis



Right forearm extensors



Right Forearm Flexors

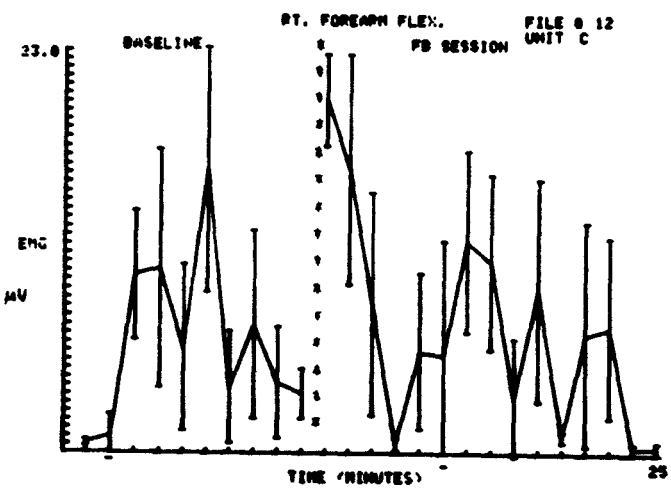


Figure 3.12: IEMG data from three muscle sites during session 9 (phase B) indicating mean ± 1 standard deviation at each minute for subject T.D.

3.2.2.2 Peripheral skin temperature

Peripheral skin temperature was measured from T.D.'s right index finger and average period mean values are shown in Figure 3.13. Very little difference occurred between the intervention period and the baseline period. During each session temperature continually rose and fell with an average range of 2.5° for the entire session. An increase in temperature is visible, however, between phase B and both A phases. This increase however cannot necessarily be attributed to the feedback as T.D.'s temperature was initially high during the no feedback baseline periods.

3.2.2.3 Respiration rate

Difficulties similar to those with B.S. were encountered in measuring T.D.'s respiration rate. T.D. had a tendancy to sweat and vigorously move his lips (athetoid movements). These factors combined to loosen the tape attaching the thermistor beneath his nostril and therefore the thermisor often moved. T.D.'s breathing was much stronger than B.S. and the TEC was more likely to record half an exhalation (ie. half an exhalation and brief inhalation followed by the rest of the exhalation). Therefore the respiration data may be somewhat unreliable. Nevertheless, period averages are shown in Figure 3.14. There are as many instances during phase B of the respiration rate increasing as decreasing in the feedback period. No conclusions can be drawn from this data.

3.2.3 Correlations between physiological parameters

Similar calculations to those done with B.S. were repeated to test the "generalization" hypothesis with T.D. Illustrated in similar matrix

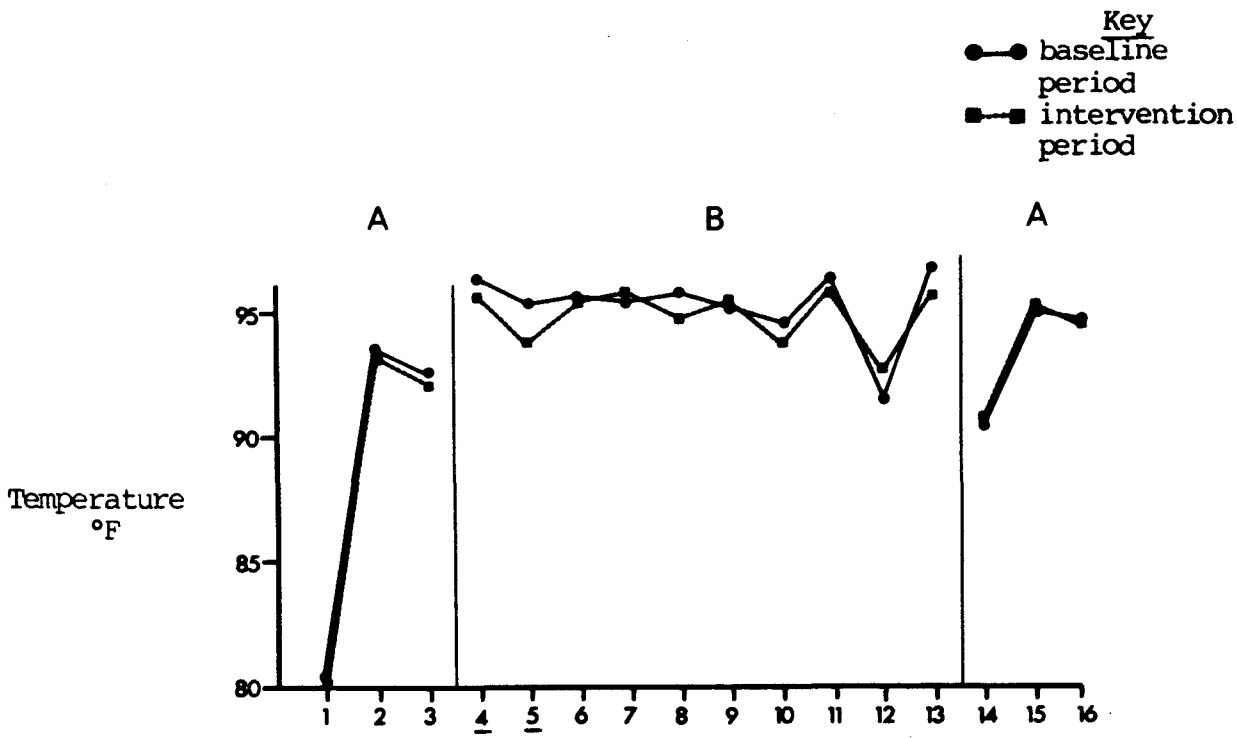


Figure 3.13: Average peripheral skin temperature mean values of the right index fingertip for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject T.D.

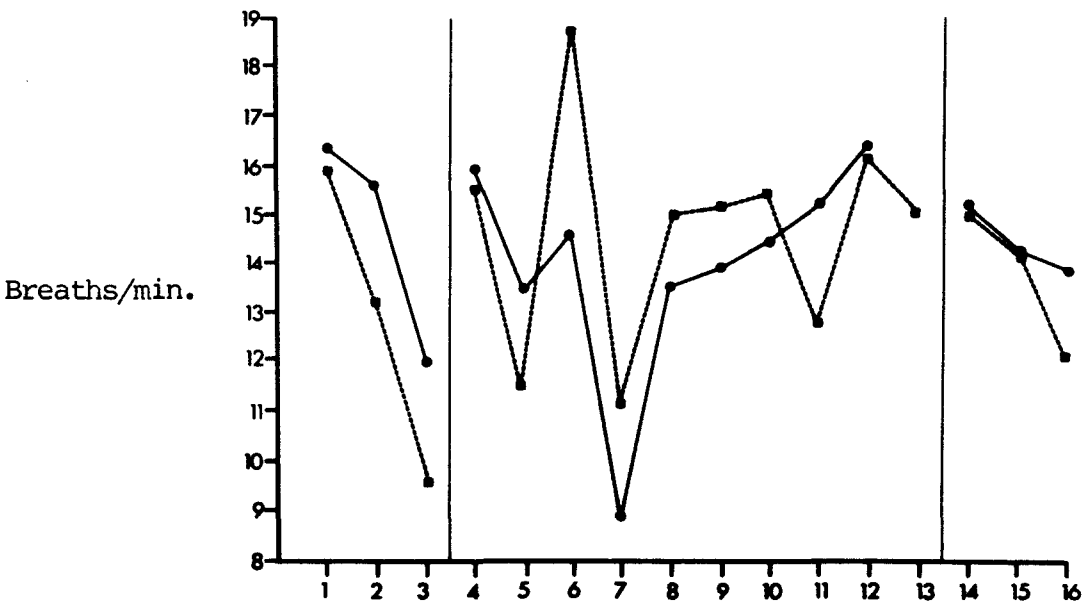


Figure 3.14: Average respiration rate means for the baseline and intervention periods across sessions with indications of significant ($P<0.05$) differences between periods for subject T.D.

CORRELATION		SESSION														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
between Mean values	AB				−							+		+			
	AC							+	+	+		+			+	+	+
	AD				−			−									
	BC		+		−												+
	BD			+	+							+	+				
	CD				−			−				+					
between SD values	AB													+			
	AC								+	+				+	+		
	AD																+
	BC													+			
	BD				+												
	CD							+									+
between Mean and SD values	AA	+	+					+	+		+		+	+			
	BB							+			+			+	+		+
	CC		−			+		+	+			+		+	+	+	
	DD	+															

Table 3.4 Significant correlations (P<0.05 indicating direction of correlation between physiological parameters for subject T.D. during baseline period (minutes 1-10)

A - frontalis EMG
B - right forearm extensor EMG
C - right forearm flexor EMG
D - right index finger temperature

CORRELATION		SESSION														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	AB				−						+		+				+
	AC					+		+	+	+	+		+		+	+	+
between	AD				+												
Mean	BC						−		+		+					+	
values	BD									+					+		
	CD								−								
	AB													+			
	AC				+	+				+	+			+		+	+
between	AD	+															
SD	BC	−		+										+	+		
values	BD			+			+							+			
	CD			+													+
	AA	+	+		+		+	+		+						+	+
between	BB			−								+		+			
Mean and	CC		−							+							
SD values	DD		−			+	−			−	+				+	−	

Table 3.5 Significant correlations (P<0.05 indicating direction of correlation between physiological parameters for subject T.D. during intervention period (minutes 16-25)

A - frontalis EMG
B - right forearm extensor EMG
C - right forearm flexor EMG
D - right index finger temperature

form in Tables 3.4 and 3.5 the significant correlation indicators provide a slightly different message than those with B.S. There are visibly far fewer significant correlations between mean values and their standard deviations and almost no correlation between forearm muscles. Most surprisingly there are a significant number of positive correlations between frontalis and forearm flexors but not extensors.

3.2.4 Evaluations

3.2.4.1a Typing: Pre-biofeedback

T.D. was able to type with the aid of his headstick from two paragraphs in a typing manual and the number of lines typed, keys hit, and errors in two 10-minute periods were counted. Results are summarized in Table 3.6.

3.2.4.1b Typing: Post-biofeedback

The task of typing with the aid of a headstick from the same two paragraphs in a typing manual as before was repeated. Again, results are presented in Table 3.6. During the first trial (first paragraph) T.D. demonstrated an improvement of 9% and in the second paragraph an improvement of 19%.

3.2.4.2a Range of motion of both shoulders: Pre-biofeedback

In examining T.D.'s right shoulder, a physiotherapist was able to achieve a range of motion (ROM) of 85° to 90° in an initial lift consisting of forward flexion through extension before spastic resistance. Continuation of forward flexion and extension until the physiotherapist could not

Measure	Pre-BFB		Post-BFB	
	Trial 1	Trial 2	Trial 1	Trial 2
# lines	11	10	11	11
# hits	321	306	351	363
# errors	33	21	24	18
error rate	10%	7%	7%	5%

Table 3.6 Summary of typing assessment with subject T.D.

overcome spasticity led to a ROM of 120°. During the first attempt, abduction of the right arm was impossible due to spasticity but a later attempt achieved an abduction ROM of 80°.

The left shoulder exhibited a ROM of 115° to 118° during forward flexion through elevation prior to spastic resistance. Full elevation of 180° was achieved when the physiotherapist forced the arm until she could not overcome spasticity. Left abductor muscles were quite tight but a 90° abduction was possible by external rotation and meeting resistance of spasticity.

3.2.4.2b Range of motion of both shoulders: Post-biofeedback

A ROM of 85° to 116° was exhibited in the right shoulder during an initial lift before first resistance by spasticity as previously described. The continuation of this lift until it was completely blocked by spasticity extended the ROM to between 116° and 123°. Abduction and external rotation of the right arm demonstrated a range of 68° to 88°.

Left shoulder ROM was 74° during initial lift that was extended to between 143° and 180° when total resistance was met. A 68° ROM was possible in the abduction maneuver.

It was evident that there was no change in T.D.'s ROM of both shoulders or in the effort required to passively move T.D.'s arms.

3.2.4.3 Questionnaire

T.D.'s sister rated his behaviour, abilities, and/or qualities comparing these since relaxation training began with the period prior to training. T.D.'s sister rather than his parents answered the questionnaire

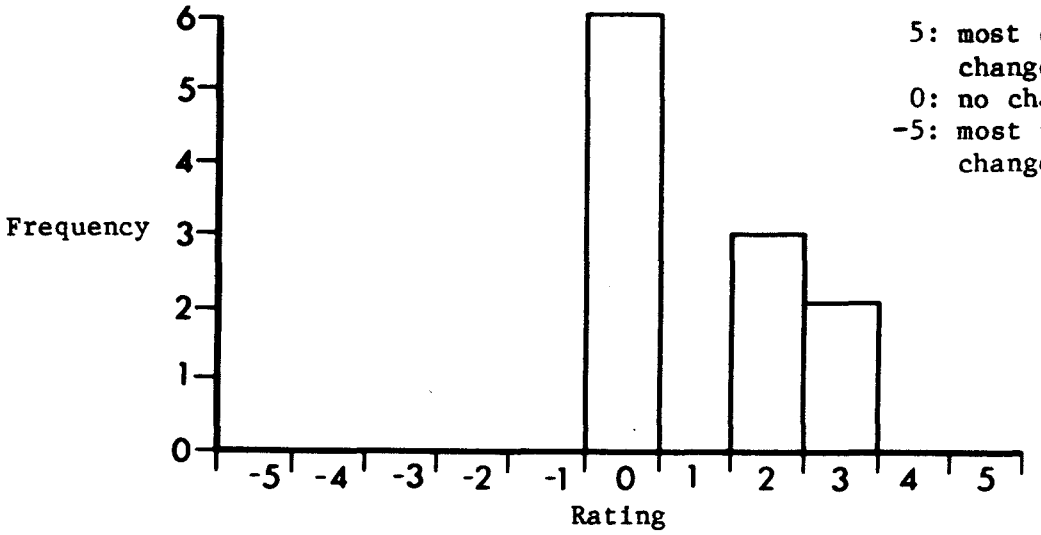
because of language problems. The same questionnaire as employed with B.S. was used. Responses are presented in Figure 3.9 in the form of a histogram for each of the three categories. All rating categories were applicable with T.D.

Ratings by his sister echoed T.D.'s comments that although he felt little physical change there had been a considerable change or alteration in his psychological state. According to his sister, he felt that he had increased his self-awareness and maturity.

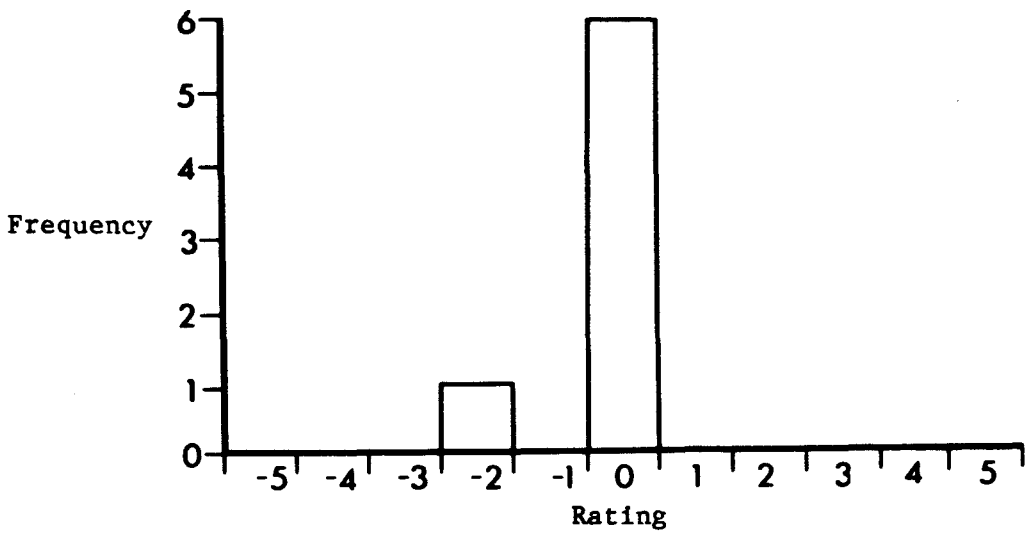
Category 1: Physical charcteristics

Rating Scale

5: most desirable change
0: no change
-5: most undesirable change



Category 2: Functional activities



Category 3: Psychosocial Activities

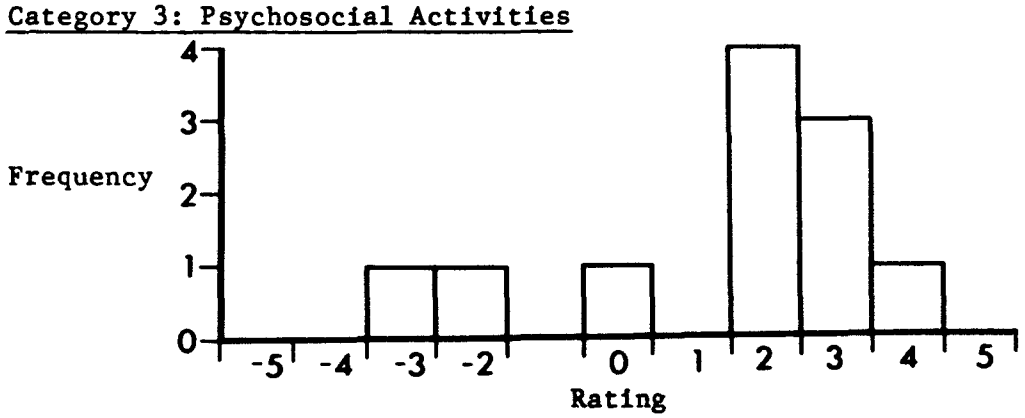


Figure 3.15: Summary of questionnaire rating T.D.'s behaviour, abilities, and quality changes since relaxation training began with the period prior to training.

CHAPTER IV

DISCUSSION

4.0 Introduction

The results from this preliminary trial of frontalis EMG feedback relaxation training with two cerebral palsy subjects are not entirely straightforward or strikingly promising. Through the employment of single-subject design methodology, the effects upon general relaxation with frontal EMG feedback alone were investigated. Physiological effects were assessed by monitoring surface EMG from frontal and forearm muscle sites, fingertip temperature and respiration rate. Clinical changes were evaluated through a variety of functional assessments and a subjective questionnaire.

Although some improvements were noted in both subjects and some interesting patterns of physiological parameters emerged, there was no clear evidence suggesting real functional improvement as a result of the training. A number of reasons may account for this and these factors will be examined in the ensuing discussion.

4.1 Single-subject design

The use of single-subject design is gaining acceptance as a scientific method for evaluating therapeutic treatments in a clinical environment. It has several distinct advantages over group studies and is particularly suited for studying treatments involving a cerebral palsy population. The manifestations of cerebral palsy are such that even though broad descriptive categories can be defined, within each category such as spastic or athetoid no two individuals will be exactly alike. Therefore, grouping cerebral palsy subjects is not always reasonable unless there is a sufficiently large population to draw from. With a limited population the heterogenity within a group is usually quite pronounced thus limiting the scientific validity of a group study.

One significant benefit of a single-subject (or single-case) design is that the subject serves as his own control. All subjects receive whatever clinical benefit is obtainable as there are no control groups and there are no problems with matching control subjects. Other advantages of employing this approach in biofeedback research include: a focus on clinical significance; the use of variability as data not error; unique methods for establishing generality of findings; and a capacity for dealing with ethical concerns in clinical research (Barlow, Blanchard, Hayes and Epstein, 1977)

The basis for utilizing a single-subject design involves using the subject as his own control and implementing different treatment interventions one at a time and establishing the effects of each intervention. In this manner there can be little doubt about the effect of a specific intervention providing that no confounding variables were inadvertently present.

Confounding variables are those environmental conditions that may positively or negatively affect the behaviour being examined. Many present therapeutic intervention theories have developed without a solid scientific basis and without discrimination between specific treatment effects and confounding variables. One consequence of this is that a therapist or clinician may conclude a false positive or a false negative outcome. A false positive is when a behaviour improves in a patient and this is causally related to the applied treatment when in fact the improvement may be the result of some other environmental factor. On the other hand, the treatment may indeed be effective while the behaviour does not appear to improve. This may possibly be due to ineffective or insensitive assessment techniques and will lead to a false negative outcome.

In this pilot study, an A-B-A single-subject design was chosen since only one variable, frontalis EMG feedback, was being tested. Both A periods contained three baseline or no-feedback sessions. This number is the minimum required to establish a trend in the data (Hersen and Barlow, 1976). Longer A periods were not employed simply because the subject found them boring and lengthening the number of sessions might have turned the subjects off the study. However, to be more scientifically rigorous, phase A_1 should have been extended until each subject reached stability. The fact that behaviours were unstable highlights the diverse nature of cerebral palsy even within a single person. Phase B was ten sessions long and in looking with hindsight this phase should also have been longer so that there would have been a greater chance for the training to impact. In addition, a second B period might have been beneficial since the subjects would not then end with a no-treatment phase.

Within each session there was a baseline period and an intervention period. Continuous auditory feedback of frontal EMG constituted the intervention in phase B while a short instruction to relax as much as possible was used in A phases. The rationale behind this design was to provide a means of comparison of behaviour independent of day-to-day differences typically seen in an individual ith cerebral palsy. It also provided a means of comparing EMG data which is affected by electrode placement and skin quality. Although it is recognized that it is difficult to compare absolute IEMG values between sessions, these values were nevertheless plotted in the results section for visual interpretation. It was felt that careful placement of the electrodes and high input impedance on the EMG unit minimized between-session variation unrelated to changes in muscle tension.

4.2 Frontalis EMG feedback and generalization theory

This pilot study was intended to replicate and extend work undertaken by Finley, Niman, Stanley, and Ender (1976) who reported the use of frontalis EMG feedback training in achieving normalization of muscle tone in six athetoid cerebral palsy patients. They noted that in addition to showing promise as a treatment in the habilitation of athetoid cerebral palsy patients, frontalis EMG feedback had significance in placing responsibility for dealing with the treatment upon the patient and not the therapist. Finley, Niman, Stanley and Wansley (1977) extended this work with four spastic palsy children but with an added dimension. This was the inclusion of explicit behaviour modification techniques with frontalis EMG feedback to form a treatment package which they coined the name "electrophysiologic behaviour modification" (EBM).

The main purpose behind EBM was to provide a system sufficiently motivating such that a child patient would be more likely to positively respond to and comply with the training. Finley and his co-workers found that this technique worked well with children and these children demonstrated increased functional abilities after training. As a result of their promising findings Finley et al put forth the argument that training frontal EMG reduction leads to generalization with corresponding relaxation at untrained muscle sites. This was substantiated by finding an initial correlation between frontal EMG and forearm flexor EMG during EBM training and by observing improvements in motor skills. Studies with normal subjects by Alexander (1975) and Freedman (1976) dispute this argument and more recently Glaus and Kotses (1979) point out that response generalization should decrease with increased training due to a continued differential reinforcement. Distinguishing the terms muscular covariation and generalization, Glaus and Kotses performed a study that indicated muscular covariation did exist but continued EMG training decreased this covariation. This decrease in covariation suggested that the response generalization function associated with EMG training was similar to other responses where generalized responding decreases with continued training and can be attributed to the discriminitive reinforcement and specificity inherent with EMG training of one muscle.

Although we recognized the fact that there was not substantial support for the theory of generalized relaxation with frontalis EMG feedback alone, the promising functional improvements seen by Finley et al (1976) and Finley et al (1977) led us to test out this approach. It was felt at the onset of this study that learning to reduce frontalis EMG activity would lead to lowered arousal with a generalizing effect of reducing

rest of the skeletal musculature. This reduction in body tone would in turn translate into increased functional control. Rather than begin with EBM it was decided to test and identify the effect of frontalis EMG feedback alone before introducing any confounding variables. In order to make a statement concerning the generalizing effects of frontalis EMG feedback, it was necessary to measure a number of physiological parameters. For this reason forearm flexor and extensor activity, peripheral skin temperature and respiration rate were monitored. Lack of further equipment limited the number of EMG monitoring sites and it is recognized that, if possible, additional sites in the lower limbs, trunk or neck muscles should have been monitored. Although not done in this study, it would also be possible to get a subjective impression by the subject as to their feelings of relaxation.

4.3 Effects of frontalis EMG training on all surface EMG measures

An examination of both B.S.'s and T.D.'s surface EMG from the frontalis and forearm sites did not reveal any dramatic improvements in absolute integrated EMG (IEMG) levels. B.S. demonstrated some ability in reducing frontalis EMG within sessions with feedback, which was reversed upon removal of feedback, but no significant generalizing effects upon the forearm extensor and flexor absolute IEMG levels were observed.

This lack of generalizing was substantiated by performing correlations between pairs of muscles and computing the significance of correlation. Although there was a high incidence of correlation between forearm flexor and extensor activity there was almost no significant correlation between frontalis activity with either forearm extensor or flexor activity. The few significant correlations that did occur were most likely coincident-

al or natural covariation. This reflects negatively upon the theory of frontalis EMG feedback aiding general relaxation, at least with this one subject. To a certain degree this can be attributed to B.S. becoming somewhat bored with the training, not paying attention to the task at hand, voluntarily moving her arms and hands about, and also playing with the feedback. This highlights the problem of frontalis EMG feedback alone not being sufficiently rewarding or motivating especially with children who have neurological damage. It was primarily for this reason that Finley et al (1977) developed the use of EBM. Although B.S. was sixteen years old it was evident that she needed something more than frontalis EMG feedback to maintain her interest.

An interesting observation, however, did stem from B.S.'s EMG data and this concerned the standard deviation values. Derived from the values used in computing minute means of IEMG, standard deviations appeared to give some additional information that was not apparent with the mean IEMG values. Rather than consider the variation within a minute period as natural fluctuation in measurement, standard deviations were examined as physiological parameters that provided a measure of the amount of variation of muscle tension. In all three sets of muscles monitored, B.S. was able to reduce absolute standard deviation levels when comparing the last session (phase A_2) with the first sessions. Most dramatic was the trend visible in frontalis standard deviations both in absolute levels across sessions and in differences between within-session feedback periods and respective baseline periods. Of special interest was the observation that during one session, mean levels of IEMG increased and standard deviations decreased, while the opposite conditions arose during another session. This underlines the im-

portance of examining muscle activity variation in addition to mean levels. It is often possible that mean levels will be seen to remain constant with feedback while variation decreases. In this case mean EMG levels are not sufficiently sensitive measures and will result in an outcome deemed unsuccessful when in fact a reduction in variability of muscle tone could be seen as a successful result. With a subject having cerebral palsy, especially one with athetoid movements, a reduction in muscle tone variability may be of prime concern when intending to improve motor functioning.

Correlation analysis between the mean level of IEMG and its standard deviation indicated in most sessions a significant ($P<0.05$) correlation, ie. higher mean levels of IEMG tended to have higher standard deviaions associated with them and vice versa. Therefore, if mean levels of IEMG are employed as indicators of muscle tone, standard deviations also have value as similar indicators. For this and for the reasons previously mentioned standard deviation may be thought of as an adjunct parameter that more fully describes muscle behaviour.

On the whole, muscular tension increased in the other subject, T.D., during the intervention period. This was a characteristic response exhibited by T.D. and was most likely the result of his trying too hard in an active sense to relax and then getting frustrated when the feedback did not respond as wished. Keats (1965) described a similar response when anxiety as well as frustration was a precursor of increased spasticity in individuals with cerebral palsy.

A roller coaster effect within T.D.'s sessions of alternating increased tone and relaxation as described in the results section illustrates the severity of his condition. Unlike B.S., this subject was much more in-

volved and could not remain relaxed when actively trying to relax for more than a few minutes at a time. The fact that T.D. was actively rather than passively trying to relax can be associated with the frontalis EMG feedback alone as the treatment intervention. As there were no specific instructions on how to relax in a passive manner, controlling the feedback placed pressure on T.D. to perform thus leading to anxiety and subsequently increased spasticity.

Few significant correlations were observed between mean IEMG levels and their associated standard deviations. Although unusual for a normal subject or even a less involved cerebral palsy individual it can be accounted for by his higher levels of spasticity. There would be minutes where T.D. would exhibit prolonged but steady muscle spasticity. In this case, high EMG mean levels would be recorded in conjunction with low standard deviations. Mulholland (1979) described the use of standard deviation in a 'control ratio' (mean/ standard deviation) which he employed as a self-regulatory index in EEG biofeedback training. If such a ratio was applied to T.D.'s EMG data it would be a wildly varying parameter even within one session as opposed to constant which is hypothesized in non-neurologically damaged subjects. Perhaps the variance of a control ratio can describe the degree of involvement of spastic cerebral palsy. A large variance may represent severe involvement and low variance mild involvement. However, much more study is required to validate such a hypothesis.

4.4 Effects of frontalis EMG biofeedback on peripheral skin temperature

It has been suggested that teaching a person to relax would be accompanied with an increase in skin temperature of the fingers. Conversely,

teaching a person to raise their fingertip temperature should aid in attaining a state of relaxation. Indeed, feelings of warmth in the extremities have been incorporated in autogenic training (Shultz & Luthe, 1969). Combining autogenic training with temperature biofeedback, successful clinical applications have been demonstrated for migraine and tension headaches. Although it was not the intent of this study to investigate temperature feedback it was thought best that fingertip temperature be monitored concurrently with the other parameters in order to test the hypothesis of increased temperature with relaxation. Unfortunately neither subject truly learned to relax.

A considerable range of baseline temperatures was observed in B.S. and during feedback phase B there was a consistent and significant ($P<0.05$) drop in temperature in the feedback period compared with baseline period. Even considering the fact that B.S. did not learn to fully relax it is still hard to account for the drop in her fingertip temperature during the feedback period compared with the baseline. A cyclic nature of baseline temperatures of varying frequency and amplitude has been described by Trusk and Jankel (1979) and was seen within and between sessions with B.S. The possibility existed for the feedback period to coincide with a decreasing temperature cycle but it would be expected that this would occur more or less in a random fashion. It is doubtful that it is mere coincidence that in 7 out of 10 sessions there was a significant decrease in temperature between the baseline and feedback period. At this time an explanation is difficult and therefore the results are simply presented.

Nothing conclusive can be drawn after inspecting T.D.'s fingertip temperature other than that cyclic patterns of rising and falling tempera-

tures similar to B.S. were noticed. There were only two significant decreases in temperature during the feedback periods and no significant increases. However, it was not surprising that T.D. did not raise his temperature as it tended to be very high in the baseline and the "ceiling effect" or physiological maximum temperature may have prevented it from going any higher even with relaxation training. Although not fully documented it is hypothesized after examining the results from B.S., T.D., and others that temperatures fluctuate more in persons with cerebral palsy than normals.

4.5 Effects of frontalis EMG biofeedback on respiration rate

As an adjunct measurement providing an index of physiological change during relaxation, respiration rate was unsatisfactory and gave only some information which was of dubious usefulness because of technical difficulties. Both subjects, especially B.S., found the wearing of a thermistor taped just below a nostril irritating. Also the thermistor had a tendency to shift with lip movements which in T.D.'s case were substantial.

Although it appeared that B.S. had significantly lowered her respiration rate near the end of the study this could be due to inaccurate recording and her mouth breathing. T.D. did not demonstrate any consistency in reducing his respiration rate with feedback and this follows from his lack of ability in controlling his spasticity.

4.6 Assessments and questionnaire

Identical pre- and post-frontalis EMG training assessments served as clinical dependent measures and were suited to each of the two subjects. Repetition of tasks was not viewed as a problem affecting post assessments.

Most of the tasks were not new to the subjects and their functional abilities had levelled off by their age. Therefore, no practice effects were anticipated. A questionnaire was also formulated in order to evaluate the clinical impact of the training. Although other assessments provided objective measures, subjective observations by an independent person such as the subject's parents should also be taken into account. To quantify these observations a number of unbiased questions were posed to be answered on an eleven point scale in three categories: physical characteristics; functional activities; and psychological factors. After the completion of the study B.S.'s parents and T.D.'s sister were asked to fill out this questionnaire comparing their behaviours, abilities, and/or qualities since relaxation training began with the period prior to training.

B.S. demonstrated some improvement in hand function and psychological measures which was somewhat surprising to the experimenters who subjectively did not perceive any improvement. However, B.S.'s parents did notice slight improvements in her physical characteristics and in her ability to relax on command. Speech evaluations indicated slight improvements in her intelligibility but no substantial gains were made and a gait study showed a loss in repeatability of her walking pattern. One unfortunate finding was B.S.'s parents reported that there was a loss in her self-concept and awareness. This is contrary to a major concept within a biofeedback paradigm, that is, an increase in self-awareness (Englehardt, 1978). However, a negative change was not entirely unexpected as she was not interested in attending to the frontalis EMG feedback and relaxation task and was in fact more interested in social interaction with the male experimenters. This lack of attention to the training may be the fault of the feedback not being suffic

iently stimulating and motivating for this particular subject. Specific relaxation strategies that kept B.S.'s concentration or EBM may have proven more successful. Nevertheless, B.S.'s social behavioural problems certainly had some bearing on the outcome and since they were not specifically dealt with they may have posed themselves as negative confounding variables.

Contrary to B.S., T.D. was described by his sister in a similar questionnaire to that answered by B.S.'s parents, as having increased his self-concept and maturity. This response was not unexpected for T.D. as he demonstrated a keen interest and desire to learn how to relax and cope with his anxieties. Admittedly, this positive change could be a placebo effect attributed to the novelty of the situation and the influence of personal conversation and support received from the experimenters during the course of the study regarding his personal anxiety problems. Certainly this presented itself as a confounding factor but for ethical concerns could not have been neglected.

Unfortunately T.D. did not exhibit any significant physical and functional improvements which were his prime reasons for attending the study. His greatest improvement was in head control as evaluated in a typing exercise but again a confounding factor was present. After each session T.D. practised with an optical scanner printing communication device that required fine head control and indeed his head control seemed to improve considerably with practice. This may have generalized to typing but both behaviours were not identical. At first T.D. was unable to print any intelligible word but by the end of the study he was able to write sentences with a very low error rate (approximately 5%). This practice with the head scanner was allowed since T.D. was in need of a communication aid and was

contemplating purchasing this unit. Clinical and ethical concerns had to take precedence over the study.

CHAPTER V

CONCLUSIONS

5.0 Summary of findings

Although no substantial improvements were seen in either B.S.'s or T.D.'s functional abilities a great deal was still learned from this pilot study relating to data acquisition and processing techniques, assessment methods and response to frontalis EMG feedback alone. With regard to the relative clinical efficacy of frontalis EMG feedback aided relaxation there is difficulty in comparing this treatment with others simply because of a lack in the availability of objective data based upon other forms of treatment.

B.S. demonstrated a learning trend to reduce mean levels of frontalis EMG but little ability in controlling her mean forearm EMG. However, she did exhibit an ability to reduce the variability of her muscle activity at all three EMG sites. This finding is significant in that it helps support the hypothesis that variability of muscle activity, as defined by the standard deviation about some mean level of EMG, may reflect the status of

self-regulation. Standard deviations were strongly correlated with their means for all muscles indicating a stable control ratio (mean/standard deviation). As B.S. was only moderately athetoid it was interesting to compare her mean/standard deviation correlations with T.D. T.D. was severely spastic and he showed fewer correlations between mean IEMG and its standard deviation ie. a variable control ratio. Also, T.D. was unable to reduce his mean EMG levels. Although further investigations are definitely required, it is suggested that the presence or lack of correlation between mean and standard deviation EMG values may be seen as an adjunct parameter in classifying cerebral palsy.

Peripheral skin temperature did not vary with feedback as expected. Rather than increase, in the case of B.S. the temperature significantly decreased. This may be accounted for by the fact that B.S. did not truly relax. Regardless, the usefulness of peripheral skin temperature as an accurate indicator of relaxation is questionable and the need for further testing is recognized.

The use of functional evaluations to assess the effectiveness of biofeedback treatment is of prime importance. However, each assessment must be relevant to the abilities of the subject and include an evaluation of whatever ability the subject would like to improve. A questionnaire answered by the subjects' immediate relatives provides a good but subjective indication (soft data) of a consumer response to the treatment. Often treatments produce significant changes but unless they are seen as beneficial by the consumer the outcome is unsuccessful. Certainly the reliability of the response can be questioned, but it is felt that the relatives responded

in a sincere and truthful manner as evidenced by even some negative changes after treatment.

Although it had been hoped that the clinical impact of this study would have been more successful, the deficiencies in the frontalis EMG feedback only treatment have been identified. These deficiencies follow:

(1) There were no specific strategies on how to relax. Both subjects were left on their own to manage the best they could using feedback as an indicator of their performance. It might be expected that, in addition to feedback, instructions such as hypnosis, progressive relaxation or autogenic suggestions which have been shown to be effective with other populations, will also have some beneficial effect with a cerebral palsy population. This, however, needs to be validated by further study.

(2) Controlling the audio feedback tended to be an active task for the two subjects. Instructions on how to passively relax while using feedback as a guide are really necessary since active tasks tend to increase anxiety and muscle tension especially in individuals with cerebral palsy.

(3) Auditory feedback alone is not a primary reinforcer and so is highly dependent upon internal motivation and comprehension. With B.S. a lack of internal motivation worked as a negative confounding variable while having good motivation and comprehension in T.D.'s case did not guarantee positive results. Perhaps a more rewarding and interesting mode of feedback would have eliminated the negative confound and influenced the results in a more positive manner.

(4) Lack of personal interaction during the session produced a 'cold' treatment atmosphere that may have had a negative effect. This unfortunately was necessary to test the efficacy of the feedback.

(5) The feedback of frontalis EMG is specific to the head and not necessarily indicative of the rest of the body. In fact, response generalization theory argues that training increases specificity of response with a decrease in other covarying responses. Therefore, frontalis EMG feedback may not be the best approach for general relaxation.

In addition to the problems with frontal EMG feedback, cited above, it is felt that there were not enough training sessions, and the training should have been more intensive, perhaps everyday.

Considering the fact that both subjects have been disabled all their lives (16 and 19 years) it may have also been unrealistic to expect that a 10-session training programme would have a significant clinical impact.

Reflecting upon all of the results it would be fair to say that frontalis EMG feedback alone was not clinically effective with the two subjects examined. It is the impression of the experimenters that changes in the protocol are necessary in order to have a clinical impact. Unfortunately, it is difficult to define exactly at what point improvements become clinically significant. There is a lack in the availability of objective data regarding changes in functional ability with other treatment modalities and so there is little to compare frontalis EMG training with.

5.1 Future considerations

The following suggestions are offered for consideration in further investigations involving EMG-aided relaxation programmes with subjects having cerebral palsy:

(1) Employ relaxation instructions/strategies in conjunction with feedback. Possibilities include: meditation, hypnosis, progressive relaxation, autogenic suggestions, concentration exercises, and imagery techniques.

(2) Utilize interesting and motivating (positive valence) feedback.

(3) Study a larger number of subjects including a control group with normal or no therapy. Alternatively, use a larger number of subjects employing single-case study methodology with each subject as his own control.

(4) Investigate the effects of relaxation and feedback training with younger children, perhaps as young as 6 years old.

(5) Examine the effects of relaxation training over a longer time period. The time course may be dependent upon improvements observed and could be considered as an experimental variable. For example, the length of time needed to reach a specific level of improvement may be indicative of the treatment efficacy. In addition, the training should be more intensive, perhaps everyday.

(6) Develop and refine functional assessment procedures so that effects of training can be more accurately assessed.

(7) Continue the use of a computer aided data acquisition system and extend its use to that of an assessment tool by interfacing it with a variety of measuring devices through which functional abilities can be evaluated.

(8) Critically examine whether relaxation is a realistic goal for the severely involved cerebral palsy individuals.

(9) Experiment with the use of muscles other than frontalis as feedback muscles. It may be more beneficial to identify a specific task to improve and use a muscle that is needed to perform this task.

(10) Develop more fully the concept of standard deviation as an index of self-regulation.

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APPENDIX A-1

CONSENT FORM

Note:- This consent form was signed by the parents of B.S. and by T.D himself

CONSENT FORM - BIOFEEDBACK STUDY

I agree to allow my son/daughter _____(name) to participate in a study relating to the use of myoelectric (EMG) biofeedback for purposes of obtaining general body relaxation. I realize that this will involve his/her attending 17 sessions of 30 - 40 minutes duration, during which time physiological measures will be taken. Forehead and forearm muscle activity and skin temperature from the great toe of the right foot will be recorded through the use of sensors attached to the skin surface by tape. Heart rate will be measured with a thimble-like device which will be attached to a toe, and respiration will be monitored using a sensor positioned close to the nostrils. I also agree to allow my son/daughter to be assessed by a physiotherapist before and after the study.

I have been informed that all information obtained by the investigators shall remain private and confidential, and that any publication or presentation arising out of this work will be designed in such a way as to insure anonymity.

I have been informed that there are no physical risks or significant discomforts involved in the procedures to be undertaken, and also that there is no guarantee of benefits to my son/daughter to be derived by participating in the study.

Notwithstanding all of the above, I understand that I may withdraw this consent and agreement at any time.

Date: _____

Parent or Guardian: _____

Witness _____

APPENDIX A-2

QUESTIONNAIRE FORM

Note:- This questionnaire was addressed to the parents of B.S. and the sister of T.D.

Dear

We would like you to take a few minutes of your time to assist us in an evaluation of possible positive or negative effects of relaxation training. It is important that you respond to all applicable items as accurately as possible, for your answers will help us to determine the effectiveness of relaxation training as a treatment approach with cerebral palsy, and the direction of future biofeedback research at the OCCC. All information obtained will be used for research purposes only and complete confidentiality will be maintained.

Please rate _____ in each of the following areas, comparing his/her behaviour, abilities, and/or qualities since relaxation training began ( ), with the period prior to training. Circle the point on each line that best indicates the degree of change which may have occurred. In each case, the mid-point represents no change and points on either side represent varying degrees of change in each possible direction. That is, points near the mid-point represent relatively small changes, whereas points at the end of each line represent a large amount of change.

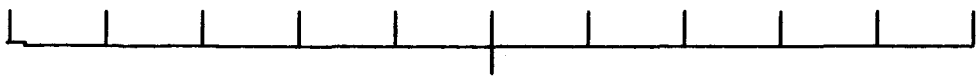
If some items are not applicable, just omit them and write N/A beside the appropriate line. If you have any questions, please do not hesitate to contact me at 425-6220, ext. 369. Please return the completed questionnaire to me, care of The Rehabilitation Engineering Department, Ontario Crippled Children's Centre, 350 Rumsey Road, Toronto, M4G 1R8. Thank you for your assistance.

Yours truly,

1.

I PHYSICAL CHARACTERISTICS

1. Muscle tone (degree of muscle tightness or tension)

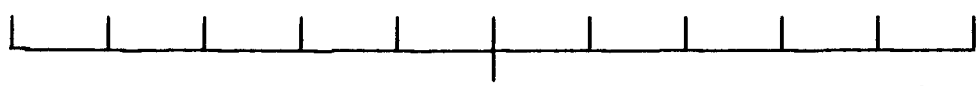


increased — no change — decreased

2. Motor control (coordination)

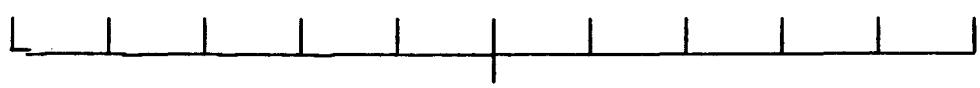
improved — no change — regressed

3. Reflex activity (e.g. bite reflex, involuntary spasms)



increased — no change — decreased

4. Ability to relax on command



improved — no change — regressed

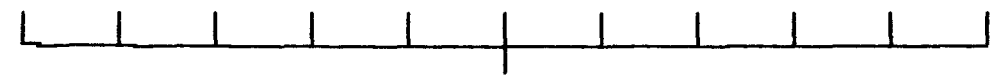
5. Number of repositionings in seat that are required

more — no change — less

6. Positioning in chair

easier — no change — more difficult

7. Physical skills (e.g. pointing, grasp and release)



lost — no change — gained

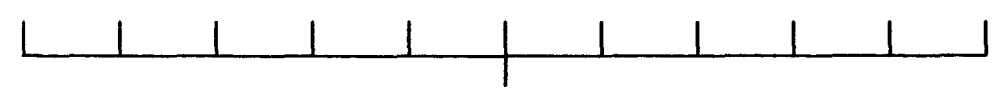
8. Sleep pattern (e.g. number of awakenings, amount of time to fall asleep)

better — no change — worse

9. Breathing pattern

improved — no change — regressed

10. Drooling



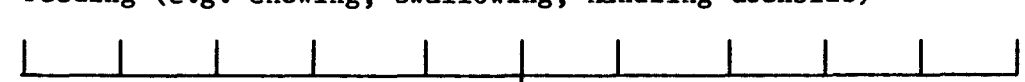
increased — no change — decreased

11. Vocalizations (sounds or speech)

more — no change — less

II. FUNCTIONAL ACTIVITIES

1. Feeding (e.g. chewing, swallowing, handling utensils)



more difficult — no change — easier

3.

2. Dressing (whether done independently or by others)

more managable — no change — less managable

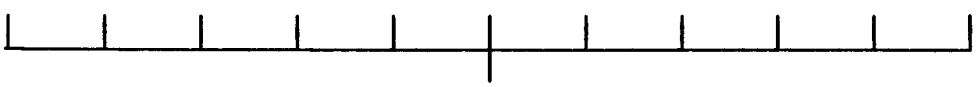
3. Communication (e.g. use of symbols, writing, typing)

more coordinated — no change — less coordinated

4. Quality of speech

less comprehensible — no change — more comprehensible

5. Independent mobility (e.g. wheelchair driving, crawling, turning over)



improved — no change — regressed

6. Transfers (e.g. from bed to wheelchair, chair to bathtub)

easier — no change — more difficult

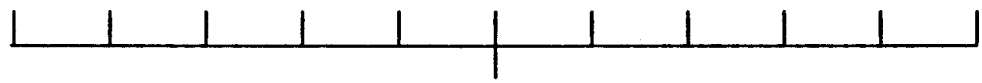
7. Gait (walking)

improved — no change — regressed

4.

III. PSYCHOSOCIAL FACTORS

1. General anxiety level (e.g. nervousness, fear, apprehension)



increased — no change — decreased

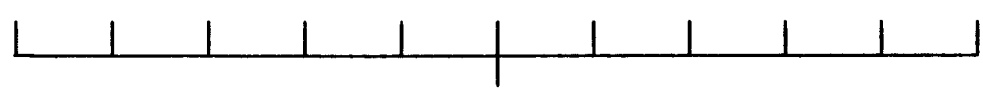
2. Ability to cope with frustration/stress

regressed — no change — improved

3. General contentment

more — no change — less

4. Maturity

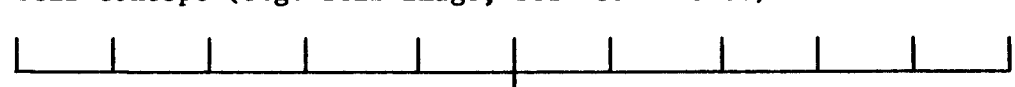


more — no change — less

5. Adapts to new situations

more readily — no change — less readily

6. Self-concept (e.g. self-image, self-confidence)



more negative — no change — more positive

5.

7. Awareness and alertness

increased — no change — decreased

8. Motivation/initiative

decreased — no change — increased

9. Irritability (crankiness, touchiness)

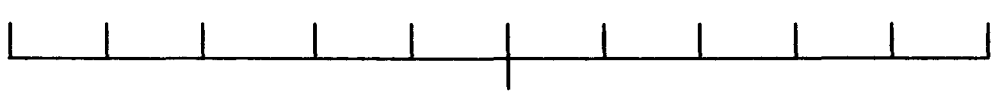
decreased — no change — increased

10. Participates in social situations (e.g. classroom, family, friends)

a)

more often — no change — less often

b)



with less ease — no change — with more ease

11. Patience

decreased — no change — increased

IV. MEDICATION

Has there been any change in medication intake? Yes ____ No ____

If yes, please try to specify both the drug and whether intake was increased or decreased.

	Type of Medication	Increased	Decreased
1.			
2.			
3.			

V. COMMENTS

Please add your own comments relating to other areas of possible change or regarding the use of relaxation training in general.

APPENDIX A-3

DATA ACQUISITION SOFTWARE

```
1 REM *** RELAX/PROM/OLDAD51 ***********************************************
2 GOSUB 100
3 WAIT
4 GOSUB 440
5 SET KEY
6 WAIT
8 REM *** DATA ACQUISITION ***
9 GOSUB 430
10 SET KEY
11 WAIT
12 REM RETURN TO DATA ACQUISITION
13 K1=K-1
14 GOSUB 720
15 WAIT
16 REM *** DATA STORAGE ***
17 GOSUB 1230
18 SET KEY
19 WAIT
20 REM DATA RETRIEVAL FROM TAPE
21 GOSUB 1420
22 SET KEY
23 WAIT
24 REM EMG GRAPH
25 GOSUB 1520
26 SET KEY
27 WAIT
28 REM TEMPERATURE GRAPH
29 GOSUB 2760
30 SET KEY
31 WAIT
32 GOSUB 3420
33 SET KEY
34 WAIT
36 PAGE
37 END
100 INIT
110 PAGE
120 PRINT '               BIOFEEDBACK RELAXATION STUDY'
130 PRINT '               ****************************'
140 PRINT ''
150 PRINT 'UDK-1: STARTS SESSION - INPUT SCALE FACTORS NOTING THAT'
160 PRINT '       (.1,.3),(1,3),(10,30) ARE EQUIVALENT AND ONLY'
170 PRINT '       .1,1,10,100 ARE TO BE TYPED'
180 PRINT '                        - INPUT BASELINE AND SESSION PERIODS'
190 PRINT ''
200 PRINT 'UDK-2: DATA ACQUISITION BEGINS WHEN THIS KEY DEPRESSED'
210 PRINT ''
220 PRINT 'UDK-3: IF DATA ACQUISITION INTERRUPTED, THIS WILL RETURN TO'
230 PRINT '       TO DATA ACQUISITION MODE'
240 PRINT ''
250 PRINT 'UDK-4: STORES DATA ON TAPE - MUSCLE NAMES, TEMP. SENSOR'
```

```
260 PRINT '        LOCATION, FILE CODE (SUBJECT'S INITIALS, SI DATE,'
270 PRINT '        EG. AA800225), AND FILE NUMBER (EG. 8), NOTING THAT'
280 PRI '       THE NUMBER MUST BE 1 GREATER THAN THE LAST FILE NUMBER'
290 PRINT ''
300 PRINT 'UDK-5: RECOVERS DATA FROM TAPE - INPUT FILE NUMBER'
310 PRINT ''
320 PRINT 'UDK-6: GRAPHS EMG DATA FOR UNITS A,B,C'
330 PRINT ''
340 PRINT 'UDK-7: GRAPHS TEMP DATA FOR UNIT D'
350 PRINT ''
360 PRINT 'UDK-8: LISTS SESSION DATA WITH CORRESPONDING FILE CODE'
370 PRINT ''
380 PRINT 'UDK-9: ENDS PROGRAM'
390 PRINT ''
400 PRINT ''
410 PRINT '*** BEGIN BY DEPRESSING UDK-1 ***'
420 SET KEY
430 RETURN
440 PAGE
450 PRINT 'ENTER SCALE FACTORS (.1,1,10,100):'
460 PRINT 'EMG UNIT A:';
470 INPUT S1
480 S1=30/S1
490 PRINT 'EMG UNIT B:';
500 INPUT S2
510 S2=30/S2
520 PRINT 'EMG UNIT C:';
530 INPUT S3
540 S3=30/S3
550 S4=7.8
560 PRINT 'BASELINE PERIOD (MINUTES):';
570 INPUT T1
580 PRINT 'FEEDBACK SESSION PERIOD:';
590 INPUT T2
600 T=T1+T2
610 SET KEY
620 RETURN
630 PAGE
640 PRINT USING 650:'TIME','EMG-A','EMG-B','EMG-C','TEMP'
650 IMAGE 4A,9X,5A, 9X,5A, 9X,5A, 9X,4A
660 B$='MEAN     SD'
670 PRINT USING 680:'MIN.',B$,B$,B$,B$
680 IMAGE 4A,5X,4(11A,3X)
690 A=0
700 T=T1+T2
710 K1=1
720 FOR K=K1 TO T
730 DELETE A
740 DIM A(240),B1(60),B2(60),B3(60),B4(60)
750 DIM Y1(T,2),Y2(T,2),Y3(T,2),Y4(T,2)
760 PRINT @16,32:'14020'
```

```
770 INPUT @16,32:A
780 I=1
790 FOR J=1 TO 240 STEP 4
800 B1(I)=A(J)/S1
810 B2(I)=A(J+3)/S2
820 B3(I)=A(J+2)/S3
830 B4(I)=A(J+1)/S4
840 I=I+1
850 NEXT J
860 C5=SUM(B1)
870 C6=SUM(B2)
880 C7=SUM(B3)
890 C8=SUM(B4)
900 B1=B1^2
910 B2=B2^2
920 B3=B3^2
930 B4=B4^2
940 C1=SUM(B1)
950 C2=SUM(B2)
960 C3=SUM(B3)
970 C4=SUM(B4)
980 Y1(K,2)=SQR((60*C1-C5^2)/3540)
990 Y2(K,2)=SQR((60*C2-C6^2)/3540)
1000 Y3(K,2)=SQR((60*C3-C7^2)/3540)
1010 Y4(K,2)=SQR((60*C4-C8^2)/3540)
1020 Y1(K,1)=C5/60
1030 Y2(K,1)=C6/60
1040 Y3(K,1)=C7/60
1050 Y4(K,1)=C8/60
1060 A1=Y1(K,1)
1070 A2=Y1(K,2)
1080 A3=Y2(K,1)
1090 A4=Y2(K,2)
1100 A5=Y3(K,1)
1110 A6=Y3(K,2)
1120 A7=Y4(K,1)
1130 A8=Y4(K,2)
1140 PRINT USING 1150:K,A1,A2,A3,A4,A5,A6,A7,A8
1150 IMAGE 2D,4X,4(3X,2D.1D,3X,2D.1D)
1160 IF K=T1 THEN 1180
1170 GO TO 1190
1180 PRINT "GGGGGGGGGGGG"
1190 NEXT K
1200 PRINT "*** DATA ACQUISITION COMPLETE ***"
1210 PRINT "GGGGGGGGGGGGGGGGGGGGGGGGGGGGGG"
1220 RETURN
1230 PAGE
1240 PRINT "*** DATA STORAGE ***"
1250 PRINT "ENTER FILE CODE:";
1260 INPUT F$
1270 PRINT "ENTER MUSCLE NAMES -"
```

```
1280 PRINT "UNIT A:";
1290 INPUT M$
1300 PRINT "UNIT B:";
1310 INPUT N$
1320 PRINT "UNIT C:";
1330 INPUT O$
1340 PRINT "TEMPERATURE SENSOR LOCATION:";
1350 INPUT P$
1360 PRINT "ENTER FILE NUMBER:";
1370 INPUT X
1380 FIND X
1390 WRITE @33:F$,M$,N$,O$,P$,T1,T2,T,Y1,Y2,Y3,Y4
1400 PRINT "*** DATA STORED ON TAPE ***"
1410 RETURN
1420 PAGE
1430 PRINT "*** DATA RETRIEVAL FROM TAPE ***"
1440 PRINT "WHAT IS FILE NUMBER?:";
1450 INPUT X
1460 FIND X
1470 READ @33:F$,M$,N$,O$,P$,T1,T2,T
1480 DIM Y1(T,2),Y2(T,2),Y3(T,2),Y4(T,2)
1490 READ @33:Y1,Y2,Y3,Y4
1500 PRINT "*** DATA RETRIEVED ***"
1510 RETURN
1520 PAGE
1530 DIM D1(T),D2(T),D3(T),D4(T)
1540 PRINT "*** EMG GRAPHIC DISPLAY ***"
1550 PRINT "WHICH UNIT IS TO BE GRAPHED?:";
1560 INPUT U$
1570 IF U$="A" THEN 1760
1580 IF U$="B" THEN 1680
1590 U$="C"
1600 Z$=O$
1610 FOR K=1 TO T
1620 D1(K)=Y3(K,1)
1630 D2(K)=D1(K)+Y3(K,2)
1640 D3(K)=D1(K)-Y3(K,2)
1650 D4(K)=Y3(K,2)
1660 NEXT K
1670 GO TO 1830
1680 Z$=N$
1690 FOR K=1 TO T
1700 D1(K)=Y2(K,1)
1710 D2(K)=D1(K)+Y2(K,2)
1720 D3(K)=D1(K)-Y2(K,2)
1730 D4(K)=Y2(K,2)
1740 NEXT K
1750 GO TO 1830
1760 Z$=M$
1770 FOR K=1 TO T
1780 D1(K)=Y1(K,1)
```

```
1790 D2(K)=D1(K)+Y1(K,2)
1800 D3(K)=D1(K)-Y1(K,2)
1810 D4(K)=Y1(K,2)
1820 NEXT K
1830 PAGE
1840 N=T-1
1850 H=D1(1)
1860 FOR I=2 TO N
1870 IF D1(I+1)=>H THEN 1890
1880 GO TO 1900
1890 H=D1(I+1)
1900 NEXT I
1910 H=INT(H+3.5)
1920 WINDOW 0,T,0,H
1930 VIEWPORT 10,120,10,90
1940 AXIS 1,0.5
1950 MOVE 1,D1(1)
1960 FOR I=2 TO T1
1970 DRAW I,D1(I)
1980 NEXT I
1990 MOVE T1+1,D1(T1+1)
2000 T3=T1+2
2010 FOR I=T3 TO T
2020 DRAW I,D1(I)
2030 NEXT I
2040 FOR K=1 TO T
2050 L=K-T*0.005
2060 M=D2(K)-H*0.015
2070 MOVE L,M
2080 PRINT "-"
2090 MOVE K,D2(K)
2100 DRAW K,D3(K)
2110 Q=D3(K)-H*0.015
2120 MOVE L,Q
2130 PRINT "-"
2140 NEXT K
2150 K=H/15
2160 MOVE T1+0.5,0
2170 FOR J=1 TO 15
2180 RMOVE 0,K
2190 PRINT "*"
2200 NEXT J
2210 WINDOW 0,130,0,100
2220 VIEWPORT 0,130,0,100
2230 MOVE 52,4
2240 PRINT "TIME (MINUTES)"
2250 MOVE 117,6
2260 PRINT T
2270 MOVE 0,50
2280 PRINT "IEMG"
2290 MOVE 0,40
```

```
2300 PRINT "dV"
2310 GOSUB 2330
2320 RETURN
2330 MOVE 2,88
2340 PRINT USING 2350:H
2350 IMAGE 2D.1D
2360 MOVE 21,90
2370 PRINT "BASELINE"
2380 MOVE 74,90
2390 PRINT "FB SESSION"
2400 MOVE 95,98
2410 PRINT F$
2420 MOVE 95,95
2430 PRINT "FILE #"
2440 MOVE 106,95
2450 PRINT X
2460 MOVE 95,92
2470 PRINT "UNIT"
2480 MOVE 105,92
2490 PRINT U$
2500 MOVE 50,95
2510 PRINT Z$
2520 S1=D1(1)
2530 S2=D4(1)
2540 FOR J=2 TO T1
2550 S1=S1+D1(J)
2560 S2=S2+D4(J)
2570 NEXT J
2580 R1=S1/T1
2590 R2=S2/T1
2600 K=T2+2
2610 S3=D1(T2+1)
2620 S4=D4(T2+1)
2630 FOR J=K TO T
2640 S3=S3+D1(J)
2650 S4=S4+D4(J)
2660 NEXT J
2670 R3=S3/T1
2680 R4=S4/T1
2690 R=R3/R1
2700 S=R4/R2
2710 MOVE 10,98
2720 PRINT USING 2730:"R=",R,"S=",S
2730 IMAGE 2A,2D.3D,5X,2A,2D.3D
2740 MOVE 0,0
2750 RETURN
2760 PAGE
2770 DIM D1(T),D2(T),D3(T)
2780 REM *** TEMPERATURE GRAPHIC DISPLAY ***
2790 FOR K=1 TO T
2800 D1(K)=Y4(K,1)
```

```
2810 D2(K)=D1(K)+Y4(K,2)
2820 D3(K)=D1(K)-Y4(K,2)
2830 D4(K)=Y4(K,2)
2840 NEXT K
2850 N=T-1
2860 H=D1(1)
2870 L=D1(1)
2880 FOR I=2 TO N
2890 IF D1(I+1)=>H THEN 2910
2900 GO TO 2920
2910 H=D1(I+1)
2920 IF D1(I+1)<=L THEN 2940
2930 GO TO 2950
2940 L=D1(I+1)
2950 NEXT I
2960 H=INT(H+1.5)
2970 L=INT(L-1.5)
2980 WINDOW 0,T,L,H
2990 VIEWPORT 10,120,10,90
3000 AXIS 1,0.5
3010 MOVE 1,D1(1)
3020 FOR I=2 TO T1
3030 DRAW I,D1(I)
3040 NEXT I
3050 MOVE T1+1,D1(T1+1)
3060 T3=T1+2
3070 FOR I=T3 TO T
3080 DRAW I,D1(I)
3090 NEXT I
3100 FOR K=1 TO T
3110 N=K-T*0.005
3120 M=D2(K)-(H-L)*0.015
3130 MOVE N,M
3140 PRINT "-"
3150 MOVE K,D2(K)
3160 DRAW K,D3(K)
3170 Q=D3(K)-(H-L)*0.015
3180 MOVE N,Q
3190 PRINT "-"
3200 NEXT K
3210 K=(H-L)/15
3220 MOVE T1+0.5,L
3230 FOR J=1 TO 15
3240 RMOVE 0,K
3250 PRINT "*"
3260 NEXT J
3270 WINDOW 0,130,0,100
3280 VIEWPORT 0,130,0,100
3290 MOVE 52,4
3300 PRINT "TIME (MINUTES)"
3310 MOVE 117,6
```

```
3320 PRINT T
3330 MOVE 0,50
3340 PRINT "TEMP."
3350 MOVE 2,10
3360 PRINT USING 3370:L
3370 IMAGE 2D.1D
3380 U$="D"
3390 Z$=P$
3400 GOSUB 2330
3410 RETURN
3420 PAGE
3430 REM *** DATA TABLE ***
3440 PRINT USING 3450:"TIME","EMG-A","EMG-B","EMG-C","TEMP"
3450 IMAGE 4A,9X,5A,9X,5A,9X,5A,9X,4A
3460 B$="MEAN      SD"
3470 PRINT USING 3480:"MIN.",B$,B$,B$,B$
3480 IMAGE 4A,5X,4(11A,3X)
3490 FOR K=1 TO T
3500 A1=Y1(K,1)
3510 A2=Y1(K,2)
3520 A3=Y2(K,1)
3530 A4=Y2(K,2)
3540 A5=Y3(K,1)
3550 A6=Y3(K,2)
3560 A7=Y4(K,1)
3570 A8=Y4(K,2)
3580 PRINT USING 3590:K,A1,A2,A3,A4,A5,A6,A7,A8
3590 IMAGE 2D,4X,4(3X,2D.1D,3X,2D.1D)
3600 NEXT K
3610 PRINT ""
3620 PRINT F$
3630 RETURN
```

APPENDIX A-4

DATA MANAGEMENT SOFTWARE

```
1 REM *** RELAX/PRGM/STATS/STUDY1.AS51 ***********************************
2 GO TO 100
4 REM *** UDK-1; PROCESSED DATA TABLE ***
5 GOSUB 2420
8 REM *** UDK-2; CONTINUE NEXT PAGE OF DATA ***
9 GO TO 2600
10 SET KEY
11 WAIT
12 REM *** UDK-3; DISPLAY CORRELATIONS - FIRST FILE ***
13 GOSUB 2420
14 SET KEY
15 WAIT
16 REM *** UDK-4; DISPLAY NEXT CORRELATIONS FROM NEXT FILE ***
17 GOSUB 3080
18 END
100 PAGE
110 INIT
120 PRINT '                BIOFEEDBACK STATISTICS'
130 PRINT '                **********************'
140 PRINT ''
150 DIM W(30)
160 PRINT 'HOW MANY FILES TO BE EXAMINED?';
170 INPUT C1
180 DIM D1(8,C1),D2(8,C1),D3(8,C1),D4(8,C1),D5(8,C1),D6(8,C1)
190 DIM B1(8,C1),B2(8,C1),B3(8,C1),B4(8,C1)
200 PRINT ''
210 DIM Z1(C1),Z2(C1),Z3(C1),Z4(C1)
220 PRINT 'WHAT ARE FILE NUMBERS AND TIME PERIODS TO BE EXAMINED?'
230 PRINT ''
240 PRINT '           example 1 1 10 16 25'
250 PRINT '              file #  RS   FBS'
260 PRINT ''
270 FOR J=1 TO C1
280 PRINT '','(';J;') ';
290 INPUT W(J),Z1(J),Z2(J),Z3(J),Z4(J)
300 NEXT J
310 FOR C=1 TO C1
320 REM *** READ DATA FROM TAPE ***
330 FIND W(C)
340 READ @33:F$,M$,N$,O$,P$,T1,T2,T
350 DIM Y1(T,2),Y2(T,2),Y3(T,2),Y4(T,2)
360 READ @33:Y1,Y2,Y3,Y4
370 PAGE
380 MOVE 0,50
390 PRINT '              *** DATA RETRIEVED FROM FILE ';W(C);' ***'
400 PRINT '                  PROCESSING IN PROGRESS'
410 DIM A(T,8)
420 FOR K=1 TO T
430 A(K,1)=Y1(K,1)
440 A(K,2)=Y1(K,2)
450 A(K,3)=Y2(K,1)
```

```
460 A(K,4)=Y2(K,2)
470 A(K,5)=Y3(K,1)
480 A(K,6)=Y3(K,2)
490 A(K,7)=Y4(K,1)
500 A(K,8)=Y4(K,2)
510 NEXT K
511 REM     B1=SUM(x)     BL
512 REM     B2=SUM(x*2)   BL
513 REM     B3=SUM(x)     FB
514 REM     B4=SUM(x*2)   FB
520 B1=0
530 B2=0
540 B3=0
550 B4=0
560 FOR I=1 TO 8
570 FOR K=Z1(C) TO Z2(C)
580 B1(I,C)=B1(I,C)+A(K,I)
590 B2(I,C)=B2(I,C)+A(K,I)^2
600 NEXT K
610 FOR J=Z3(C) TO Z4(C)
620 B3(I,C)=B3(I,C)+A(J,I)
630 B4(I,C)=B4(I,C)+A(J,I)^2
640 NEXT J
650 NEXT I
660 REM     T3= LENGTH OF BASELINE PORTION EXAMINED
670 REM     T4= LENGTH OF FEEDBACK PORTION EXAMINED
680 T3=Z2(C)-Z1(C)+1
690 T4=Z4(C)-Z3(C)+1
700 REM     D1= AVERAGE VALUE OF BASELINE
710 REM     D2= AVERAGE VALUE OF FEEDBACK
720 REM     D3= ABSOLUTE DIFFERENCE BETWEEN AVERAGE VALUES OF FB & BL
730 REM     D4= % DIFFERENCE BETWEEN AVERAGE VALUES OF FB & BL
740 REM     D5= STANDARD DEVIATION OF BL VALUES
750 REM     D6= STANDARD DEVIATION OF FB VALUES
760 FOR I=1 TO 8
770 D1(I,C)=B1(I,C)/T3
780 D2(I,C)=B3(I,C)/T4
790 D3(I,C)=D2(I,C)-D1(I,C)
800 D4(I,C)=(D2(I,C)/D1(I,C)-1)*100
810 X1=T3*B2(I,C)-B1(I,C)^2
820 X2=T4*B4(I,C)-B3(I,C)^2
830 D5(I,C)=SQR(X1/(T3*(T3-1)))
840 D6(I,C)=SQR(X2/(T4*(T4-1)))
850 NEXT I
860 REM ***************** BASELINE SESSION *******************************
870 REM     E,F= SUM(xy)
880 REM     G,H= (SUM(xy) - SUM(x)SUM(y)/N)/(N-1) = Sxy
890 REM     I,J= Sxy/SxSy = Rxy
900 DIM E1(C1),E2(C1),E3(C1),E4(C1),E5(C1),E6(C1),E7(C1),E8(C1),E9(C1)
910 DIM E0(C1),F1(C1),F2(C1),F3(C1),F4(C1),F5(C1),F6(C1),G1(C1),G2(C1)
920 DIM G3(C1),G4(C1),G5(C1),G6(C1),G7(C1),G8(C1),G9(C1),G0(C1),H1(C1)
```

```
930 DIM H2(C1),H3(C1),H4(C1),H5(C1),H6(C1),I1(C1),I2(C1),I3(C1),I4(C1)
940 DIM I5(C1),I6(C1),I7(C1),I8(C1),I9(C1),I0(C1),J1(C1),J2(C1),J3(C1)
950 DIM J4(C1),J5(C1),J6(C1)
960 E1=0
970 E2=0
980 E3=0
990 E4=0
1000 E5=0
1010 E6=0
1020 E7=0
1030 E8=0
1040 E9=0
1050 F0=0
1060 F1=0
1070 F2=0
1080 F3=0
1090 F4=0
1100 F5=0
1110 F6=0
1120 FOR K=Z1(C) TO Z2(C)
1130 E1(C)=E1(C)+A(K,1)*A(K,3)
1140 E2(C)=E2(C)+A(K,1)*A(K,5)
1150 E3(C)=E3(C)+A(K,1)*A(K,7)
1160 E4(C)=E4(C)+A(K,3)*A(K,5)
1170 E5(C)=E5(C)+A(K,3)*A(K,7)
1180 E6(C)=E6(C)+A(K,5)*A(K,7)
1190 E7(C)=E7(C)+A(K,1)*A(K,2)
1200 E8(C)=E8(C)+A(K,3)*A(K,4)
1210 E9(C)=E9(C)+A(K,5)*A(K,6)
1220 E0(C)=E0(C)+A(K,7)*A(K,8)
1230 F1(C)=F1(C)+A(K,2)*A(K,4)
1240 F2(C)=F2(C)+A(K,2)*A(K,6)
1250 F3(C)=F3(C)+A(K,2)*A(K,8)
1260 F4(C)=F4(C)+A(K,4)*A(K,6)
1270 F5(C)=F5(C)+A(K,4)*A(K,8)
1280 F6(C)=F6(C)+A(K,6)*A(K,8)
1290 NEXT K
1300 REM ************************************************************************
1310 G1(C)=(E1(C)-B1(1,C)*B1(3,C)/T3)/(T3-1)
1320 G2(C)=(E2(C)-B1(1,C)*B1(5,C)/T3)/(T3-1)
1330 G3(C)=(E3(C)-B1(1,C)*B1(7,C)/T3)/(T3-1)
1340 G4(C)=(E4(C)-B1(3,C)*B1(5,C)/T3)/(T3-1)
1350 G5(C)=(E5(C)-B1(3,C)*B1(7,C)/T3)/(T3-1)
1360 G6(C)=(E6(C)-B1(5,C)*B1(7,C)/T3)/(T3-1)
1370 G7(C)=(E7(C)-B1(1,C)*B1(2,C)/T3)/(T3-1)
1380 G8(C)=(E8(C)-B1(3,C)*B1(4,C)/T3)/(T3-1)
1390 G9(C)=(E9(C)-B1(5,C)*B1(6,C)/T3)/(T3-1)
1400 G0(C)=(E0(C)-B1(7,C)*B1(8,C)/T3)/(T3-1)
1410 H1(C)=(F1(C)-B1(2,C)*B1(4,C)/T3)/(T3-1)
1420 H2(C)=(F2(C)-B1(2,C)*B1(6,C)/T3)/(T3-1)
1430 H3(C)=(F3(C)-B1(2,C)*B1(8,C)/T3)/(T3-1)
```

```
1440 H4(C)=(F4(C)-R1(4,C)*R1(6,C)/T3)/(T3-1)
1450 H5(C)=(F5(C)-R1(4,C)*R1(8,C)/T3)/(T3-1)
1460 H6(C)=(F6(C)-R1(6,C)*R1(8,C)/T3)/(T3-1)
1470 I1(C)=G1(C)/(D5(1,C)*D5(3,C))
1480 I2(C)=G2(C)/(D5(1,C)*D5(5,C))
1490 I3(C)=G3(C)/(D5(1,C)*D5(7,C))
1500 I4(C)=G4(C)/(D5(3,C)*D5(5,C))
1510 I5(C)=G5(C)/(D5(3,C)*D5(7,C))
1520 I6(C)=G6(C)/(D5(5,C)*D5(7,C))
1530 I7(C)=G7(C)/(D5(1,C)*D5(2,C))
1540 I8(C)=G8(C)/(D5(3,C)*D5(4,C))
1550 I9(C)=G9(C)/(D5(5,C)*D5(6,C))
1560 I0(C)=G0(C)/(D5(7,C)*D5(8,C))
1570 J1(C)=H1(C)/(D5(2,C)*D5(4,C))
1580 J2(C)=H2(C)/(D5(2,C)*D5(6,C))
1590 J3(C)=H3(C)/(D5(2,C)*D5(8,C))
1600 J4(C)=H4(C)/(D5(4,C)*D5(6,C))
1610 J5(C)=H5(C)/(D5(4,C)*D5(8,C))
1620 J6(C)=H6(C)/(D5(6,C)*D5(8,C))
1630 REM ****************** FEEDBACK SESSION ******************************
1640 REM     K,L= SUM(xy)
1650 REM     M,N= (SUM(xy) - SUM(x)SUM(y)/N)/(N-1) = Sxy
1660 REM     O,P= Sxy/SxSy = Rxy
1670 DIM K1(C1),K2(C1),K3(C1),K4(C1),K5(C1),K6(C1),K7(C1),K8(C1),K9(C1)
1680 DIM K9(C1),K0(C1),L1(C1),L2(C1),L3(C1),L4(C1),L5(C1),L6(C1),M1(C1)
1690 DIM M2(C1),M3(C1),M4(C1),M5(C1),M6(C1),M7(C1),M8(C1),M9(C1),M0(C1)
1700 DIM N1(C1),N2(C1),N3(C1),N4(C1),N5(C1),N6(C1),O1(C1),O2(C1),O3(C1)
1710 DIM O4(C1),O5(C1),O6(C1),O7(C1),O8(C1),O9(C1),O0(C1),P1(C1),P2(C1)
1720 DIM P3(C1),P4(C1),P5(C1),P6(C1)
1730 K1=0
1740 K2=0
1750 K3=0
1760 K4=0
1770 K5=0
1780 K6=0
1790 K7=0
1800 K8=0
1810 K9=0
1820 K0=0
1830 L1=0
1840 L2=0
1850 L3=0
1860 L4=0
1870 L5=0
1880 L6=0
1890 FOR K=Z3(C) TO Z4(C)
1900 K1(C)=K1(C)+A(K,1)*A(K,3)
1910 K2(C)=K2(C)+A(K,1)*A(K,5)
1920 K3(C)=K3(C)+A(K,1)*A(K,7)
1930 K4(C)=K4(C)+A(K,3)*A(K,5)
1940 K5(C)=K5(C)+A(K,3)*A(K,7)
```

```
1950 K6(C)=K6(C)+A(K,5)*A(K,7)
1960 K7(C)=K7(C)+A(K,1)*A(K,2)
1970 K8(C)=K8(C)+A(K,3)*A(K,4)
1980 K9(C)=K9(C)+A(K,5)*A(K,6)
1990 K0(C)=K0(C)+A(K,7)*A(K,8)
2000 L1(C)=L1(C)+A(K,2)*A(K,4)
2010 L2(C)=L2(C)+A(K,2)*A(K,6)
2020 L3(C)=L3(C)+A(K,2)*A(K,8)
2030 L4(C)=L4(C)+A(K,4)*A(K,6)
2040 L5(C)=L5(C)+A(K,4)*A(K,8)
2050 L6(C)=L6(C)+A(K,6)*A(K,8)
2060 NEXT K
2070 REM ************************************************************************
2080 M1(C)=(K1(C)-B3(1,C)*B3(3,C)/T4)/(T4-1)
2090 M2(C)=(K2(C)-B3(1,C)*B3(5,C)/T4)/(T4-1)
2100 M3(C)=(K3(C)-B3(1,C)*B3(7,C)/T4)/(T4-1)
2110 M4(C)=(K4(C)-B3(3,C)*B3(5,C)/T4)/(T4-1)
2120 M5(C)=(K5(C)-B3(3,C)*B3(7,C)/T4)/(T4-1)
2130 M6(C)=(K6(C)-B3(5,C)*B3(7,C)/T4)/(T4-1)
2140 M7(C)=(K7(C)-B3(1,C)*B3(2,C)/T4)/(T4-1)
2150 M8(C)=(K8(C)-B3(3,C)*B3(4,C)/T4)/(T4-1)
2160 M9(C)=(K9(C)-B3(5,C)*B3(6,C)/T4)/(T4-1)
2170 M0(C)=(K0(C)-B3(7,C)*B3(8,C)/T4)/(T4-1)
2180 N1(C)=(L1(C)-B3(2,C)*B3(4,C)/T4)/(T4-1)
2190 N2(C)=(L2(C)-B3(2,C)*B3(6,C)/T4)/(T4-1)
2200 N3(C)=(L3(C)-B3(2,C)*B3(8,C)/T4)/(T4-1)
2210 N4(C)=(L4(C)-B3(4,C)*B3(6,C)/T4)/(T4-1)
2220 N5(C)=(L5(C)-B3(4,C)*B3(8,C)/T4)/(T4-1)
2230 N6(C)=(L6(C)-B3(6,C)*B3(8,C)/T4)/(T4-1)
2240 O1(C)=M1(C)/(D6(1,C)*D6(3,C))
2250 O2(C)=M2(C)/(D6(1,C)*D6(5,C))
2260 O3(C)=M3(C)/(D6(1,C)*D6(7,C))
2270 O4(C)=M4(C)/(D6(3,C)*D6(5,C))
2280 O5(C)=M5(C)/(D6(3,C)*D6(7,C))
2290 O6(C)=M6(C)/(D6(5,C)*D6(7,C))
2300 O7(C)=M7(C)/(D6(1,C)*D6(2,C))
2310 O8(C)=M8(C)/(D6(3,C)*D6(4,C))
2320 O9(C)=M9(C)/(D6(5,C)*D6(6,C))
2330 O0(C)=M0(C)/(D6(7,C)*D6(8,C))
2340 P1(C)=N1(C)/(D6(2,C)*D6(4,C))
2350 P2(C)=N2(C)/(D6(2,C)*D6(6,C))
2360 P3(C)=N3(C)/(D6(2,C)*D6(8,C))
2370 P4(C)=N4(C)/(D6(4,C)*D6(6,C))
2380 P5(C)=N5(C)/(D6(4,C)*D6(8,C))
2390 P6(C)=N6(C)/(D6(6,C)*D6(8,C))
2400 NEXT C
2410 RETURN
2420 REM ********** PROCESSED DATA TABLE SUBROUTINE ********************
2430 FOR I=1 TO 8
2440 PAGE
2450 PRINT "*** ";I;"***"
```

```
2460 PRINT ""
2470 V$="SD BL"
2480 X$="SD FS"
2490 PRINT USING 2500:"FILE","AVG BL","AVG FS","CHANGE","%CHANGE",V$,X$
2500 IMAGE 3X,4A,7X,6A,4X,6A,4X,6A,5X,7A,5X,5A,5X,5A
2510 PRINT ""
2520 FOR C=1 TO C1
2530 PRI USI 2540:W(C),D1(I,C),D2(I,C),D3(I,C),D4(I,C),D5(I,C),D6(I,C)
2540 IMAGE 4X,2D,3X,2(5X,2D.2D),5X,+2D.2D,5X,+3D.2D,2(5X,2D.2D)
2550 NEXT C
2560 MOVE 0,10
2570 PRINT '                    *** PRESS UDK-2 TO CONTINUE ***'
2580 SET KEY
2590 WAIT
2600 NEXT I
2610 RETURN
2620 REM ********** CORRELATION SUBROUTINE ****************************
2630 FOR C=1 TO C1
2640 PAGE
2650 PRINT 'FILE: ';W(C)
2660 PRINT ""
2670 PRINT '                      CORRELATION COEFFICIENTS '
2680 PRINT ""
2690 PRINT 'Baseline Period Examined:';Z1(C);"-";Z2(C);" min."
2700 PRINT 'Feedback Period Examined:';Z3(C);"-";Z4(C);" min."
2710 PRINT ""
2720 PRINT '                            BASELINE PERIOD'
2730 PRINT 'MEAN VALUES'
2740 PRINT USING 2750:"Rab=",I1(C),"Rac=",I2(C),"Rad=",I3(C)
2750 IMAGE 3(4A,+1D.2D,15X)
2760 PRINT USING 2770:"Rbc=",I4(C),"Rbd=",I5(C),"Rcd=",I6(C)
2770 IMAGE 3(4A,+1D.2D,15X)
2780 PRINT ""
2790 PRINT 'STANDARD DEVIATION VALUES'
2800 PRINT USING 2810:"Rab=",J1(C),"Rac=",J2(C),"Rad=",J3(C)
2810 IMAGE 3(4A,+1D.2D,15X)
2820 PRINT USING 2830:"Rbc=",J4(C),"Rbd=",J5(C),"Rcd=",J6(C)
2830 IMAGE 3(4A,+1D.2D,15X)
2840 PRINT ""
2850 PRINT 'MEAN-STANDARD DEVIATION VALUES'
2860 PRI USI 2870:"Raa=",I7(C),"Rbb=",I8(C),"Rcc=",I9(C),"Rdd=",I0(C)
2870 IMAGE 4(4A,+1D.2D,12X)
2880 PRINT ""
2890 PRINT '                          FEEDBACK PERIOD'
2900 PRINT ""
2910 PRINT 'MEAN VALUES'
2920 PRINT USING 2930:"Rab=",O1(C),"Rac=",O2(C),"Rad=",O3(C)
2930 IMAGE 3(4A,+1D.2D,15X)
2940 PRINT USING 2950:"Rbc=",O4(C),"Rbd=",O5(C),"Rcd=",O6(C)
2950 IMAGE 3(4A,+1D.2D,15X)
2960 PRINT ""
```

```
2970 PRINT "STANDARD DEVIATION VALUES"
2980 PRINT USING 2990:"Rab=",P1(C),"Rac=",P2(C),"Rad=",P3(C)
2990 IMAGE 3(4A,+1D.2D,15X)
3000 PRINT USING 3010:"Rbc=",P4(C),"Rbd=",P5(C),"Rcd=",P6(C)
3010 IMAGE 3(4A,+1D.2D,15X)
3020 PRINT ""
3030 PRINT "MEAN-STANDARD DEVIATION VALUES"
3040 PRI USI 3050:"Raa=",07(C),"Rbb=",08(C),"Rcc=",09(C),"Rdd=",00(C)
3050 IMAGE 4(4A,+1D.2D,12X)
3060 SET KEY
3070 WAIT
3080 NEXT C
3090 RETURN
```

APPENDIX A-5

EMG PROCESSING

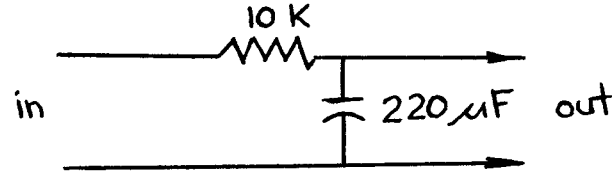
EMG Processing

With regard to the arrangement of two active and one reference electrodes per muscle site rather than one reference electrode for all sites, this is a particular arrangement by the manufacturer of the myographs.

The processing of the filtered EMG is unique to Autogen myograph systems and is referred to as integral averaging. The filtered EMG is rectified, integrated, and scaled/divided by the time constant of integration, which in the Autogen 1700 is 50 milliseconds, and the output signal is called instantaneous integrated EMG (IEMG). This process is said to be superior to peak-to-peak and RMS methods for EMG feedback applications and "the integral average amplitude is the constant DC voltage which will transfer a charge equivalent to that of the electrical waveform".¶ It has been defined by the formula:

$$A_{avg} = \frac{\int_0^T |a|\,dt}{T}$$

In order to smooth the instantaneous IEMG so that it could be sampled at 1.25 Hz., it was necessary to construct an RC circuit through which the instantaneous IEMG passed prior to sampling by the Tektronix 4051 computer. The following circuit was used:



¶Freeman, J.A. Integral average, RMS, and peak-to-peak: A comparison of EMG detection techniques. Autogenic System Incorporated, Berkeley, California, 1976.